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Durability Evaluation of the Effects of Hydro-processed Renewable Jet (HRJ) blended at 50% with petroleum JP-8 on a Navistar Maxxforce D10 9.3L Engine

May 2012

U.S. Army Tank Automotive Research,
Development, and Engineering Center
Detroit Arsenal
Warren, Michigan 48397-5000

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The alternative fuels tests were conducted by the U.S. Army's Tank Automotive Research, Development and Engineering Center (TARDEC), Ground Vehicle Power & Mobility (GVPM) team, utilizing a test cell in building 212. The test was started in April 2011 and was completed in March 2012.

The purpose of the test was to compare the performance and 400 hour durability of an engine using a synthetic fuel blend (HRJ and JP-8) to that fueled by the standard military fuel, JP-8.

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Two Navistar 9.3L diesel engines were tested to a modified version of the NATO 400-hr test. Test modifications included using non-standard fuels (JP-8 and a JP-8/HRJ fuel blend) and elevated testing temperatures. Engine #1 was endurance tested on JP-8 fuel while engine #2 was endurance tested on JP-8/HRJ fuel blend. Both engines completed the 400 hour endurance schedule successfully. In addition, the data for both engines shows that there is a small decrease in engine power output from JP-8 to JP-8/HRJ blended fuel proportionate with decreasing fuel volumetric energy.

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1.0 INTRODUCTION / BACKGROUND

To comply with US Army Regulation 70-12, Fuels and Lubricants Standardization Policy for Equipment Design, Operation and Logistic Support, the US Army TARDEC's GVPM group, Fuels and Lubricants Technology Team, and National Automotive Center (NAC) have cooperated to test and evaluate synthetic (non-petroleum crude) based fuel usage in diesel engines. Ultimately, results from this testing, along with other evaluations, will be used to determine the suitability of blending synthetically derived kerosene with petroleum kerosene fuels such as Jet-A and Jet Propellant-8 (JP-8). Previous diesel engine testing performed at TARDEC was with a blend of Fischer-Tropsch (FT) derived Synthetic Paraffinic Kerosene (SPK) and petroleum JP-8. The testing described in this report was also conducted with an SPK and JP-8 blend; however, this SPK was derived from a different manufacturing process that hydro-processes esters and fatty acids produced from plant oils and animal fats. This SPK is now known as Hydro-processed Esters and Fatty Acids (HEFA) SPK, and initially was called Hydro-processed Renewable Jet (HRJ). The HRJ fuel being tested will be delivered for testing as a prescription 50/50 blend (vol.) of HEFA SPK and JP-8 meeting the military specification for JP-8 (MIL-DTL-83133H). For the remainder of this document it will be referred to as "HRJP-8."

The tests contained within this report will be used to assess the effect of the HRJP-8 fuel on engine performance and durability as compared to JP-8. This evaluation requires that two similar engines of make and model be tested, one on JP-8 and the other on the blended fuel. The engines were subjected to the 400 hour NATO (AEP-5) test procedure at elevated temperatures for both the JP-8 and HRJP-8 fuels.

2.0 OBJECTIVE

The purpose of this testing is to quantitatively measure any changes in engine performance, durability or operating characteristic as compared to 100% JP-8 and to also better understand the overall durability of the subject engine. The subject engine for this test is a Navistar Inc. MAXXFORCE D10/9.3L I-6 used to power the Navistar Mine Resistant Ambush Protected (MRAP) military vehicle. The test procedure and cycle is a modified version of the NATO Document AEP-5 Ver. 3 (aka NATO 400 Hour Durability). Modifications to this procedure are primarily increases to the operating temperatures of the engine coolant, combustion air and fuel supply to extremes observed during actual vehicle usage called Desert Operating Conditions (DOC). The focus will be on the engine's entire fuel system. This consists of the fuel delivery system (lines, filter and low pressure pump), seals and fuel injectors (hydraulically-actuated unit type). Strict adherence to the pass/fail criteria of the NATO AEP-5 will not be followed since the focus of this testing is on identifying performance similarities and differences between DF-2, JP-8 and HRJP-8 as well as gathering general engine durability information.

The first engine will perform a durability cycle on JP-8 and the second engine will follow performing a durability cycle on the HRJP-8 fuel. Prior to the start of the durability cycle, each engine will undergo a break-in procedure and full load performance evaluations to baseline performance on DF-2, JP-8 and HRJP-8 fuels at both standard NATO AEP-5 and the modified DOC temperatures.

All testing was performed in a controlled lab environment using stationary dynamometers at the US Army TARDEC-Warren facility. Both engines were tested at Standard (STD) and DOC NATO conditions during the full load performance tests conducted at 100 hour intervals.

During the 400 hour endurance portion of the NATO test, settings for DOC consisted of intake air temperature at 120^{o}F and the supply fuel temperature at 175^{o}F for engines #1 & #2. For the performance 100-hr intervals of the test, the engines ran a standard and hot full load power run where the temperatures settings were as follows: Standard NATO settings were; 77^{o}F intake air, 86^{o}F supply fuel, and for the Hot Performance; 120^{o}F intake air, 175^{o}F supply fuel.

3.0 CONCLUSIONS

Both engines completed the modified 400 hour NATO endurance test successfully without major or minor failure and retained greater than 95% of their original peak rated power only when installing new injectors at the 400 hour performance run. From a durability perspective, the engine tear-down analysis showed that engine #2 had an older style of valve guide material which allowed the valves to become loose over time and thus created high blow-by values. This material difference was based on visual inspections of the components by the author, customer, technician, and Navistar field engineer. A material change to the valve guides has already been implemented by Navistar, the engine manufacturer, to fix this issue and was represented in engine #1 which had lower valve guide wear and blow-by values.

Tables 1-4 show realistic trends when comparing power and fuel volumetric energy differences between JP-8 and HRJP-8 at standard and DOC. Any variations in these trends are within the range of the instrumentation uncertainties. The data within these tables indicate that there is a small decrease in power from JP-8 to the HRJP-8 blend and that this result stems from the energy difference in the HRJP-8 fuel being lower than that of the JP-8 fuel.

4.0 ENGINE SPECIFICATIONS

The description of the Navistar MaxxForce D10 Diesel Engine, with a rating of 375 bhp is provided in the engine data tabulation as follows:

Engine Data

ITEM	Description
TYPE	Four cycle, liquid-cooled, turbocharged with air to water after cooler, compression ignition engine
VALVE CONFIGURATION	4 valves per cylinder
ARRANGEMENT	Inline-6
BORE & STROKE	4.59 x 5.75 in
DISPLACEMENT VOLUME	570 in^3 (9.3 Liters)
FUEL SYSTEM	Electro-Hydraulic Generation 2 fuel injection
POWER RATING	375 bhp at 2000 rpm
ROTATION	Right-hand (clockwise viewed from front)
MAXIMUM TORQUE	1250 lb-ft at 1200 rpm
DRY UNIT WEIGHT	1560 lb
FIRING ORDER	1-5-3-6-2-4

5.0 LUBRICATING OIL

The engine lubricating oil used throughout this testing was grade SAE 15W-40 per MIL-PRF-2104 specification.

6.0 FUELS

Two different fuels were used for conducting endurance testing. JP-8 fuel was used during the endurance portion of testing with the first engine. A fuel blend of JP-8 and HRJ (HRJP-8) blended in a 50/50 by volume ratio was used for testing with the second engine. For the performance tests conducted at 100 hour intervals with both engines, three different fuels were used for reference purposes and they were: DF-2, JP-8, and a 50/50 blend designated HRJP-8.

The fuels are officially regulated as follows:
DF-2 per ASTM D975
JP-8 per MIL-DTL-83133
HRJP-8 Blend per MIL-DTL-83133-H-Table I and Table BII

7.0 TEST EQUIPMENT

All controls, data acquisition equipment, dynamometers, and associated equipment used in this test program were located in test cell 1 in building 212, US Army TARDEC-Warren, MI. Additional test equipment and set-up information can be found in Appendix 1. Figures 1-4 show detailed views of the engine installation from different angles.

Figure 1, Front View

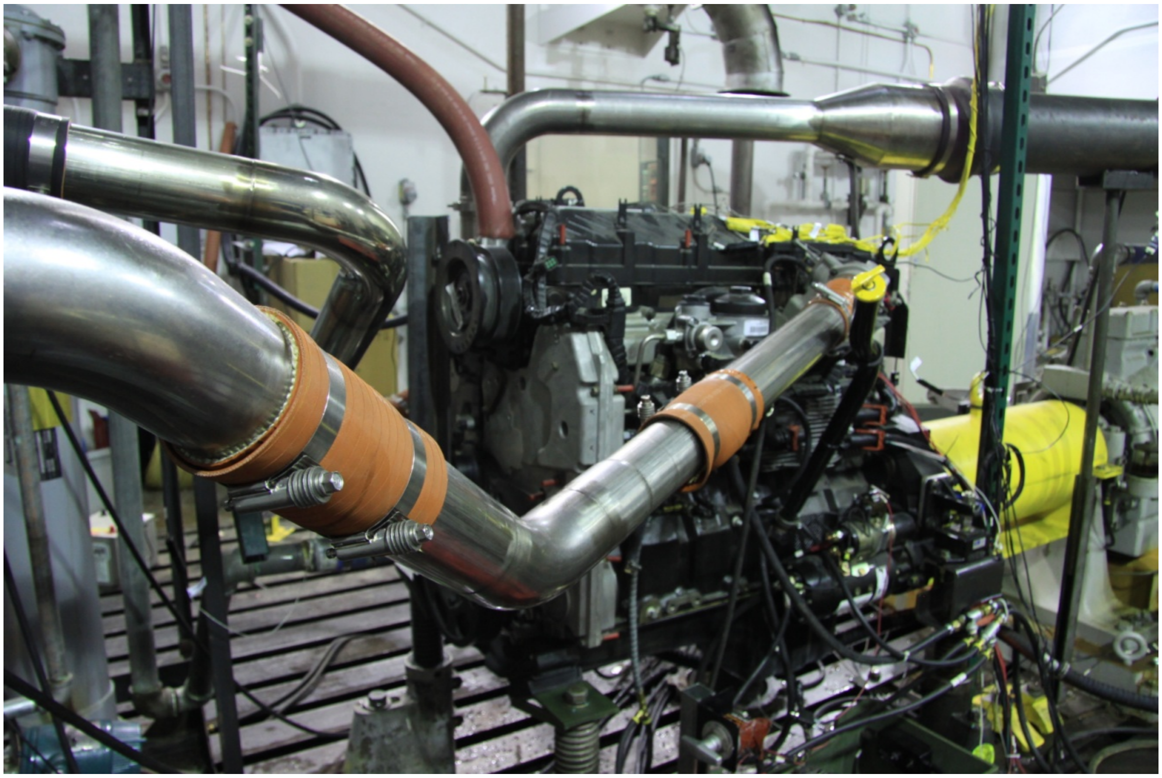


Figure 2, Rear View

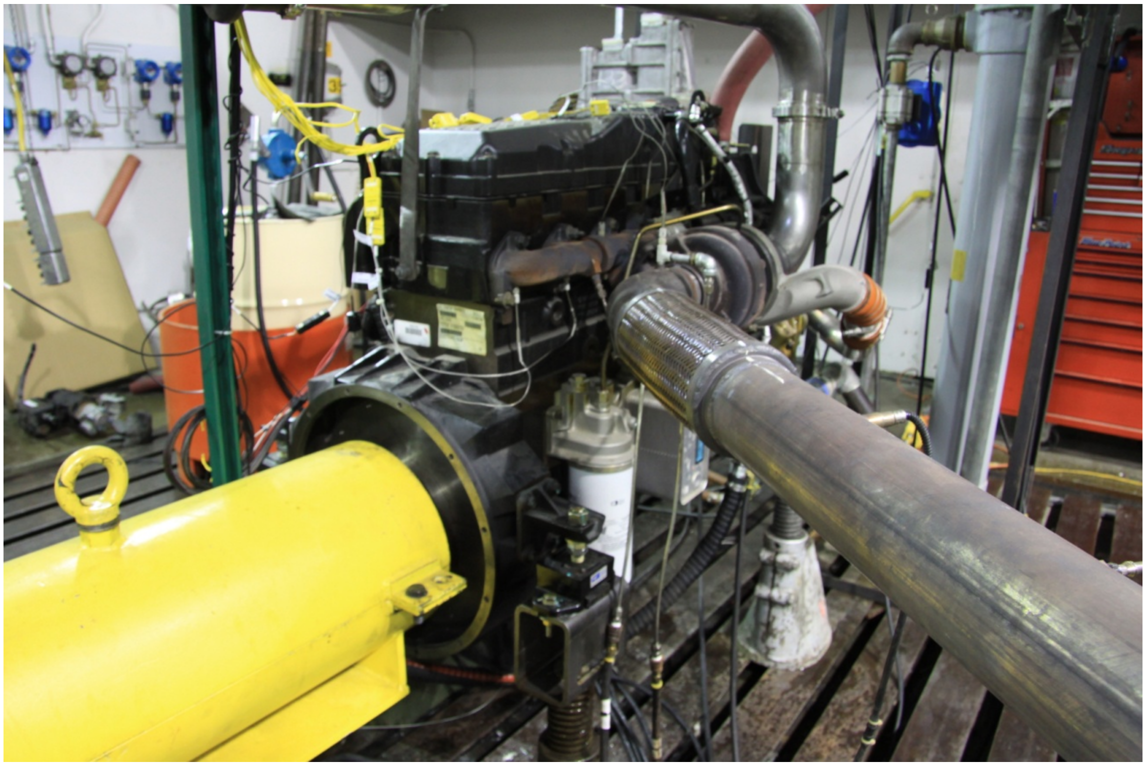


Figure 3, Right Side View

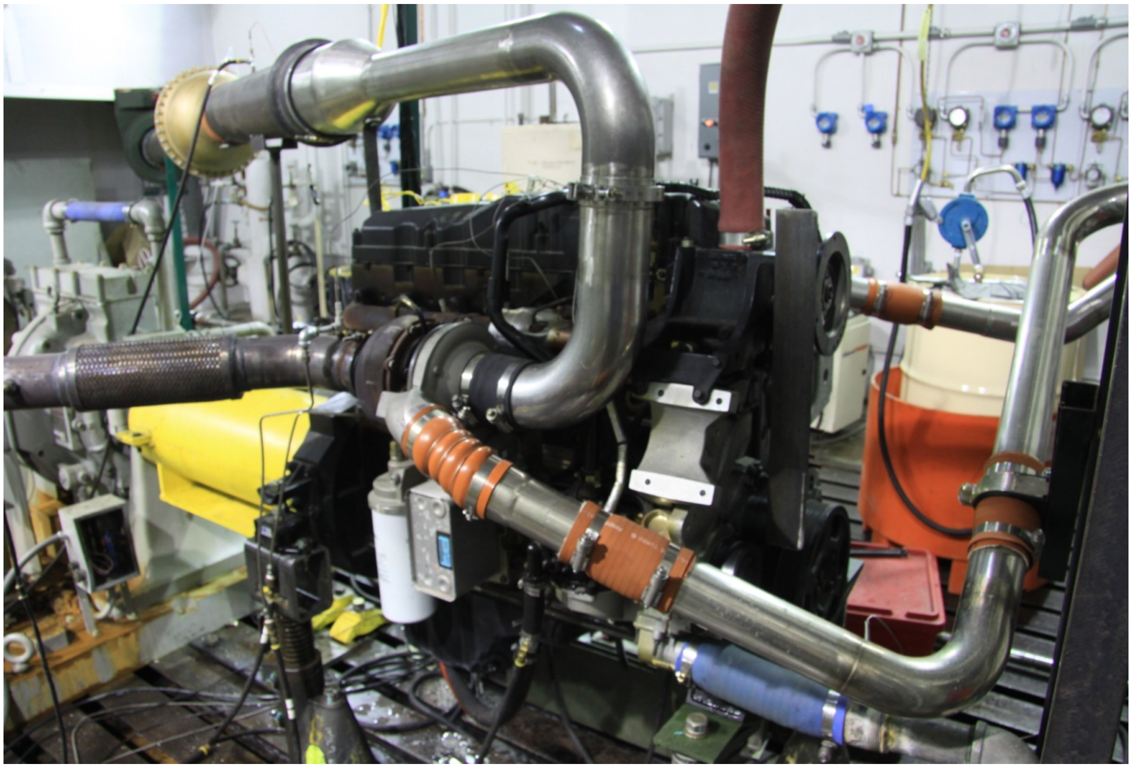
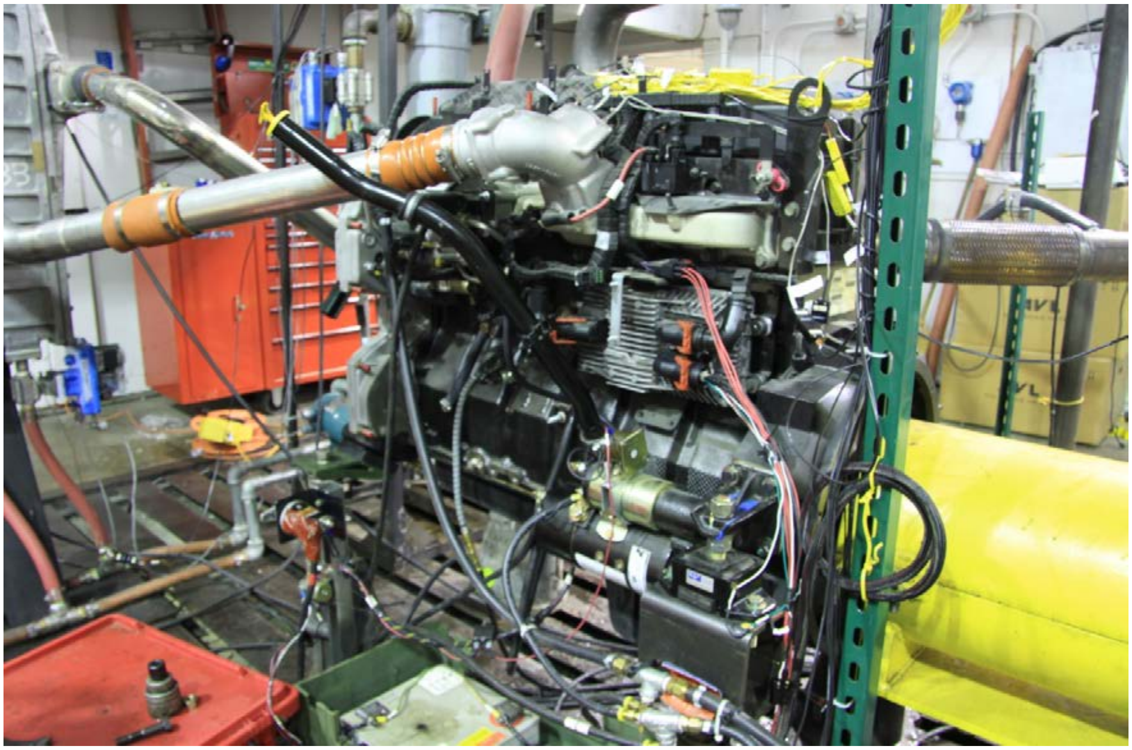


Figure 4, Left Side View



8.0 TEST PROCEDURE

Test procedures for the performance and endurance segments of the tests are located in the Test Plan found in Appendix 1. All engine operating parameters and limits (with the exception of test temperatures) were set in accordance with NATO AEP-5 test conditions for the test duration as specified in the Test Plan (Appendix 1).

9.0 DISCUSSION

The 375 bhp Navistar MaxxForce D10 diesel engine is a representative engine from the Army's MRAP wheeled vehicle.

9.1 PERFORMANCE EVALUATION USING BASELINE JP-8 FUEL – ENGINE #1

All data are presented as observed without correction. Test conditions are described as follows: Prior (0 hrs) and post (400 hrs) test full load and part load data sweeps were conducted for standard fuel (86ºF) and ambient air (77ºF) conditions and elevated desert operating conditions (DOC) of 175ºF and 120ºF for fuel and ambient air, respectively. These performance runs are documented in full load power vs. engine speed graphs shown in Figures 5-6. The legends in the figures show two numbers in parenthesis next to each item. The first number is the true maximum value from the data regardless of engine rpm while the second number is the value at rated speed, 2,000 rpm for rated power and fuel flow and the values for torque and BSFC are at 1,200 rpm, which is the engine's rated torque rpm. These values will be discussed in the following discussion. The data for engine #1 for prior 0 test hours was repeated with a new ECU unit and for post 400 hours was repeated with new fuel injectors to determine if the existing ECU or the fuel injectors were a factor in the engine's demonstrated power output. The data showed no meaningful difference in the engine's power output when the ECU was replaced with another unit. This test report will not compare engine performance results between engines #1 and #2 due to the expected variation between two similar engines of the same type.

Engine #1 – True maximum values regardless of engine rpm:
Full load peak power under standard NATO conditions (86ºF fuel and 77ºF ambient air – Fig. 5) for JP-8 fuel at the pre 0 and post 400 hr intervals indicated 368 and 349 bhp, respectively. This represents a power decrease of 5.2%. However, when the same comparison is made between pre 0 and post 400 hr intervals using the data set for new fuel injectors at post 400 hours, the data indicates 368 and 363 bhp, respectively. This represents a power decrease of only 1.4%. This relatively small decrease over time with the new fuel injectors indicates that the majority of the 5.2% loss in the earlier comparison is due to the functional degradation of the original fuel injectors. Full load peak power under elevated DOC conditions (175ºF fuel and 120ºF ambient air – Fig. 6) for JP-8 fuel at the pre 0 and post 400 hr intervals indicated 351 and 331 bhp, respectively. This represents a power decrease of 5.7% at the end of the test. When the same comparison is made between pre 0 and post 400 hr intervals using the data set for new fuel injectors at post 400 hours, the data indicates 351 and 342 bhp, respectively. This represents a power decrease of only 2.6%. This full load power output decrease over time with new fuel injectors indicates that the majority of the 5.7% loss in the earlier comparison is due to the functional degradation of the original fuel injectors. Since passing the 400 hr NATO Endurance Test requires the engine to produce at least 95% of its rated power after 400 hrs, the resulting power decrease for engine #1 indicates a successful completion while operating on JP-8 fuel at standard and DOC conditions only if the fuel injectors are replaced at post 400 hours. Additionally, the baseline engine's rated power measured at 349 bhp after 400 hrs for standard NATO conditions, on JP-8 fuel, is 93.1% of its advertised 375 bhp (DF-2) rating. With new injectors installed at post 400 hours, the engine developed 363 bhp on JP-8 fuel, which represents 96.8% of its advertised 375 bhp (DF-2) rating. Therefore, the functional degradation of the factory installed injectors after operating for over 400 engine test hours accounts for the major loss in power and could ultimately determine if this particular engine would be able to pass a 400 hr NATO style endurance test when operating on JP-8 fuel.

Engine #1 – Values at rated power (2,000rpm) and rated torque (1,200rpm):
Full load rated power under standard NATO conditions (86ºF fuel and 77ºF ambient air – Fig. 5) for JP-8 fuel at the pre 0 and post 400 hr intervals indicated 359 and 340 bhp, respectively. This represents a power decrease of 5.3%. However, when the same comparison is made between pre 0 and post 400 hr intervals using the data set for new fuel injectors at post 400 hours, the data indicates 359 and 356 bhp, respectively. This represents a power decrease of only 0.84%. This relatively small decrease over time with the new fuel injectors indicates that the majority of the 5.3% loss in the earlier comparison is due to the functional degradation of the original fuel injectors. Full load rated power under elevated DOC conditions (175ºF fuel and 120ºF ambient air – Fig. 6) for JP-8 fuel at the pre 0 and post 400 hr intervals indicated 341 and 323 bhp, respectively. This represents a power decrease of 5.3% at the end of the test. When the same comparison is made between pre 0 and post 400 hr intervals using the data set for new fuel injectors at post 400 hours, the data indicates 341 and 335 bhp, respectively. This represents a power decrease of only 1.8%. This full load power output decrease over time with new fuel injectors indicates that the majority of the 5.3% loss in the earlier comparison is due to the functional degradation of the original fuel injectors. Since passing the 400 hr NATO Endurance Test requires the engine to produce at least 95% of its rated power after 400 hrs, the resulting power decrease for engine #1 indicates a successful completion while operating on JP-8 fuel at standard and DOC conditions only if the fuel injectors are replaced at post 400 hours. Additionally, the baseline engine's rated power measured at 340 bhp after 400 hrs for standard NATO conditions, on JP-8 fuel, is 90.7% of its advertised 375 bhp (DF-2) rating. With new injectors installed at post 400 hours, the engine developed 356 bhp on JP-8 fuel, which represents 94.9% of its advertised 375 bhp (DF-2) rating. Therefore, the functional degradation of the factory installed injectors after operating for over 400 engine test hours accounts for the major loss in power and could ultimately determine if this particular engine would be able to pass a 400 hr NATO style endurance test when operating on JP-8 fuel.

The full load BSFC values for standard NATO and elevated NATO (DOC) testing conditions are presented in Figs. 7 and 8, respectively. With the exception of some portions of a curve just crossing over another curve due to reading errors in the mass weigh beaker system, the BSFC values are representative and consistent with expected numbers for this engine operating on the fuels indicated.

The full load fuel consumption rate for standard and elevated (DOC) NATO testing conditions are presented in Figs. 9 and 10, respectively. The graphs show the fuel consumption rate increasing with engine speed at the expected rate of change.

The full load engine torque for standard and elevated NATO conditions are presented in Figs. 11 and 12, respectively. These figures show torque versus speed curves which are following expected trends similar to the power curves.

The charts for the energy difference at standard and elevated temperatures after 400 hours show good trends when comparing power and fuel volumetric energy differences. Tables 1 and 2 (for standard and DOC, respectively) show that the energy difference between JP-8 and the HRJP-8 fuel varied by 2.30 to 2.55 percent, but the variation is hard to quantify because the uncertainties with some of the instrumentation also vary as much as 2 to 3 percent. The power data shows to have varied by less than 2 percent, but the variation in power and energy difference between the two fuels are very small. The data does show that there is a small decrease in power from JP-8 to the HRJP-8 fuel, and this is a result from the energy difference in the blended fuel being lower than that of the JP-8 fuel.

Figure 5

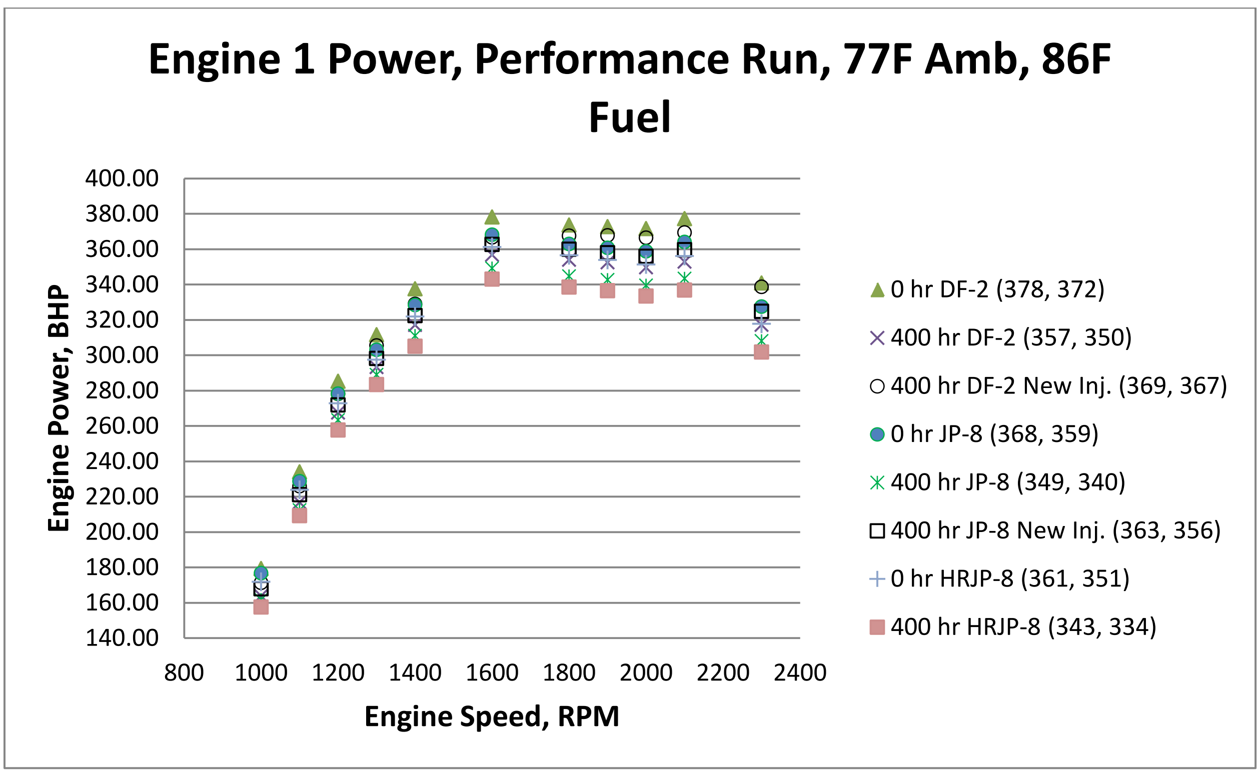


Figure 6

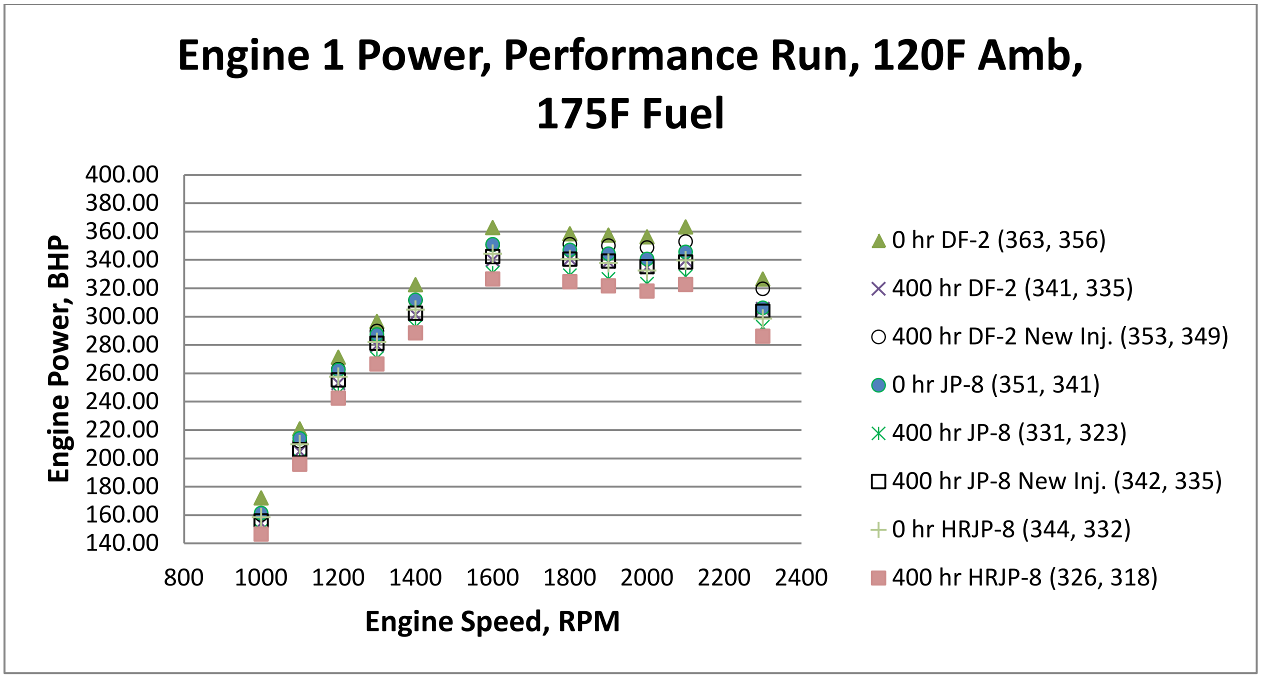


Figure 7

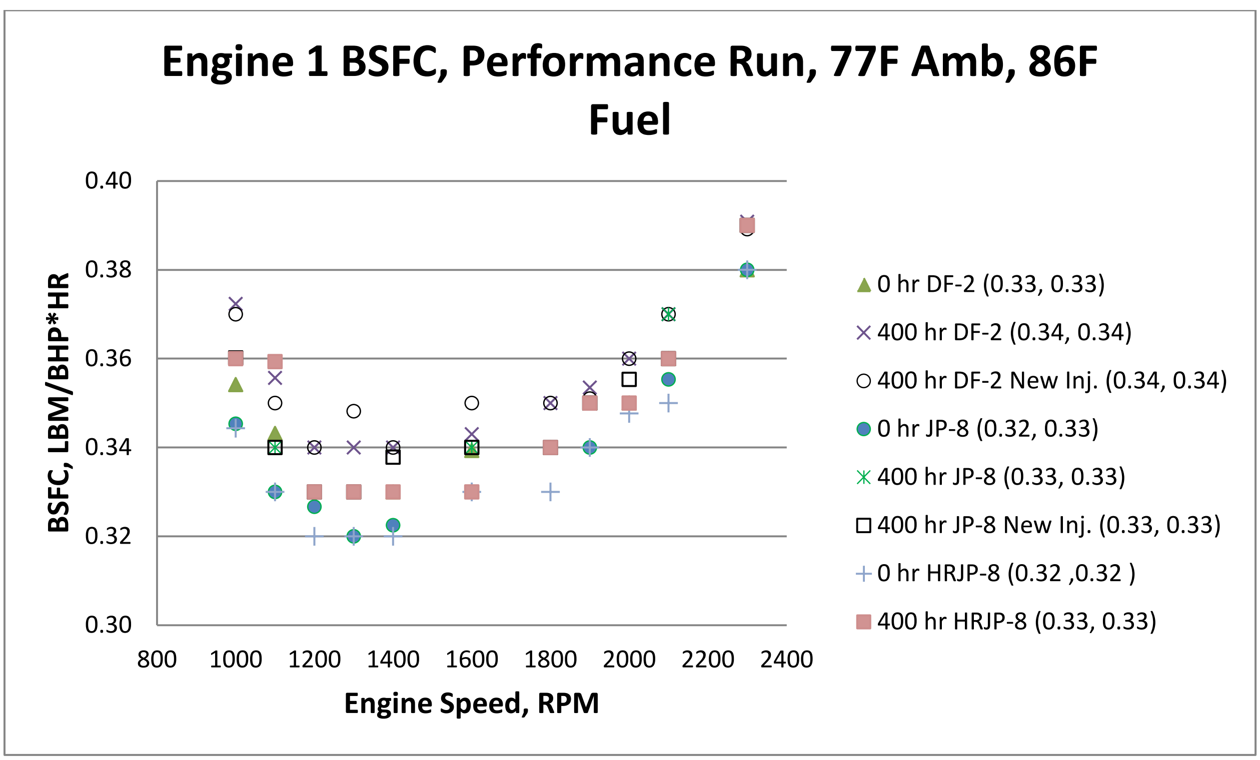


Figure 8

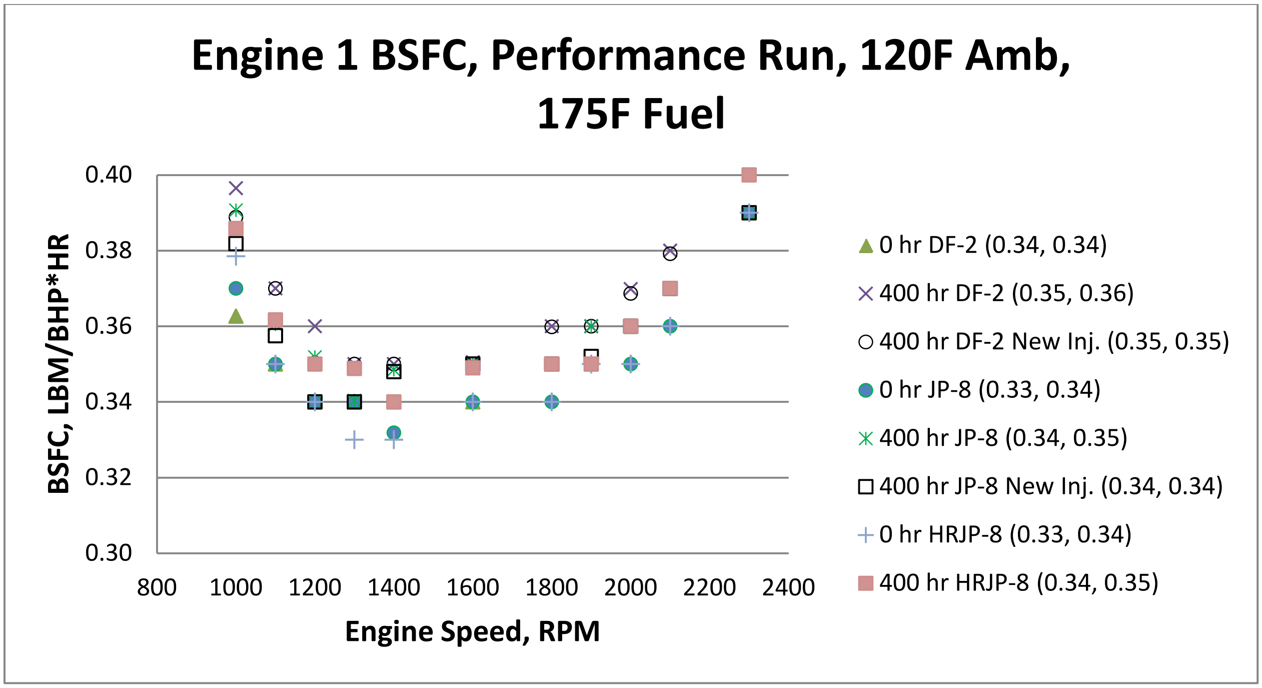


Figure 9

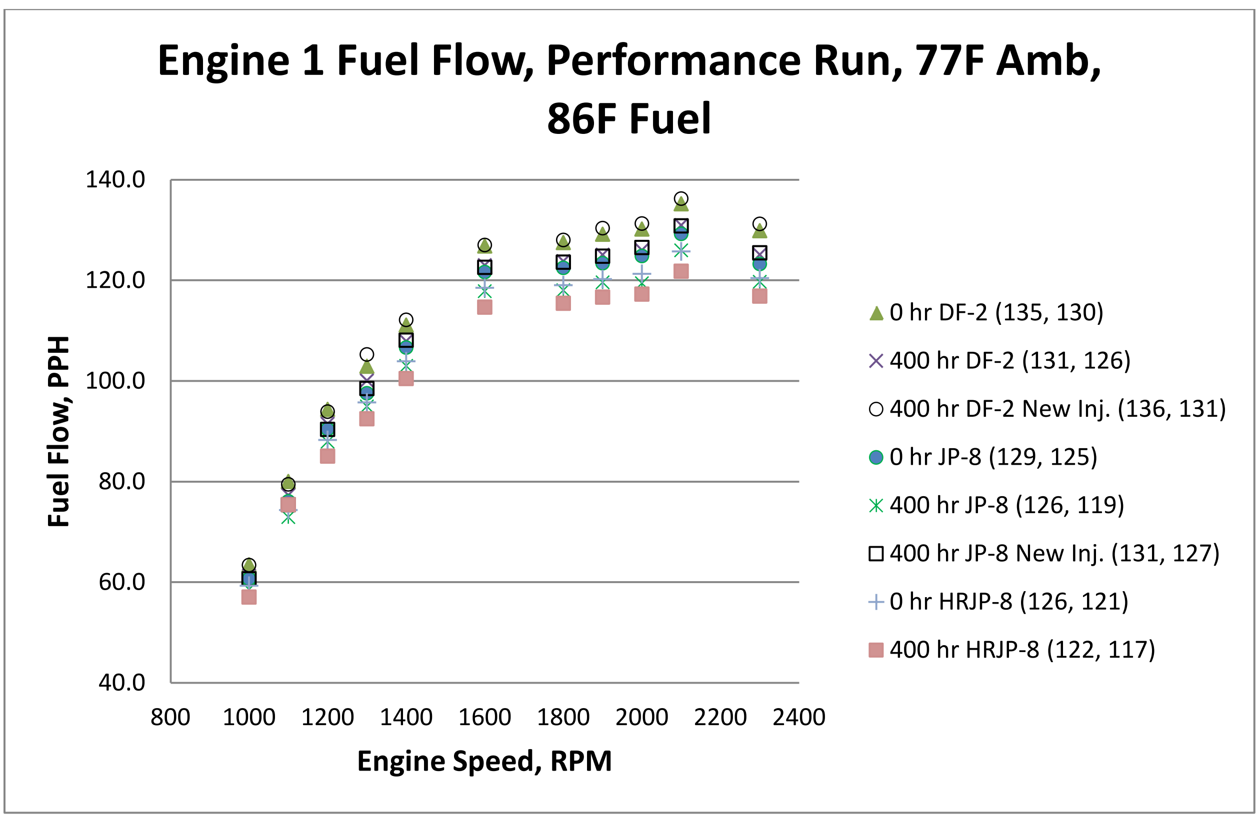


Figure 10

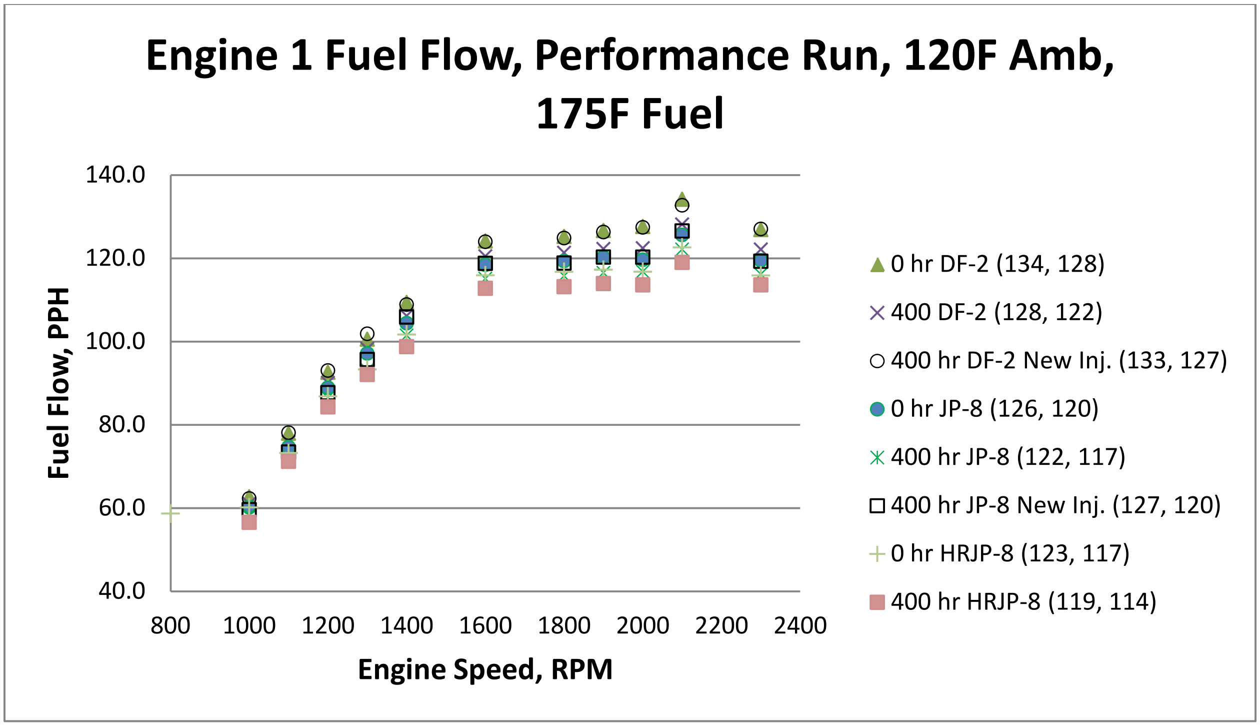


Figure 11

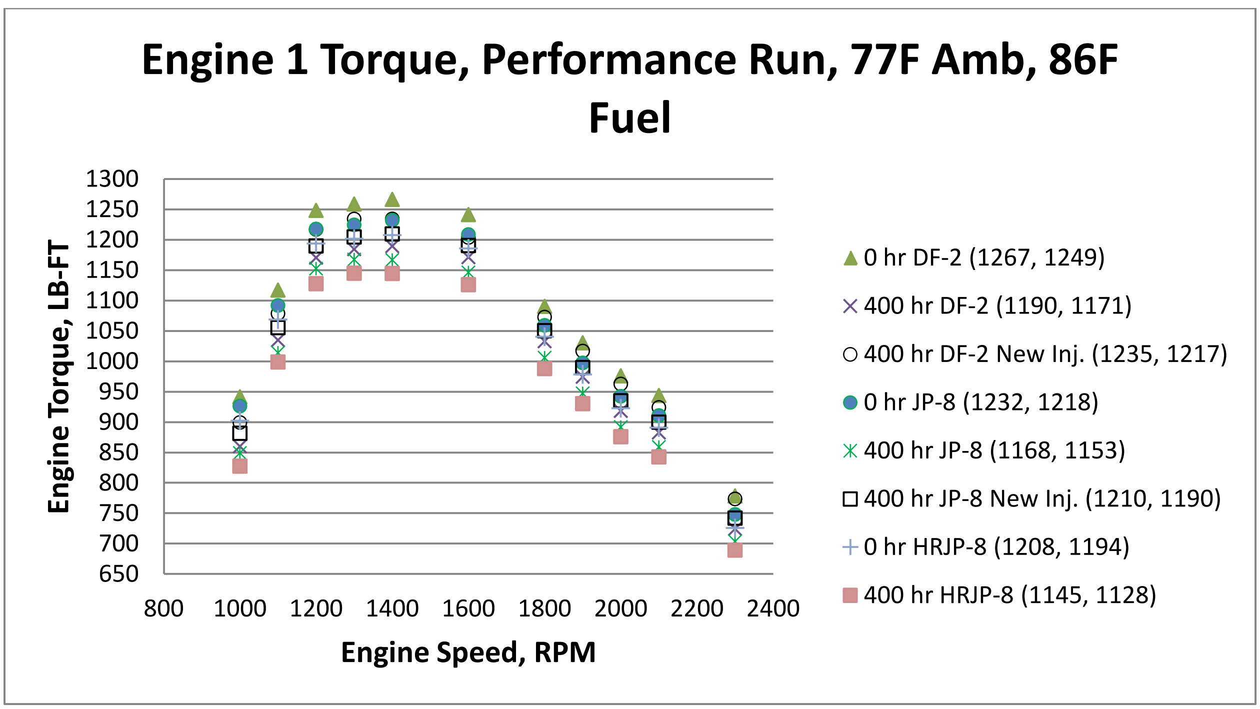


Figure 12

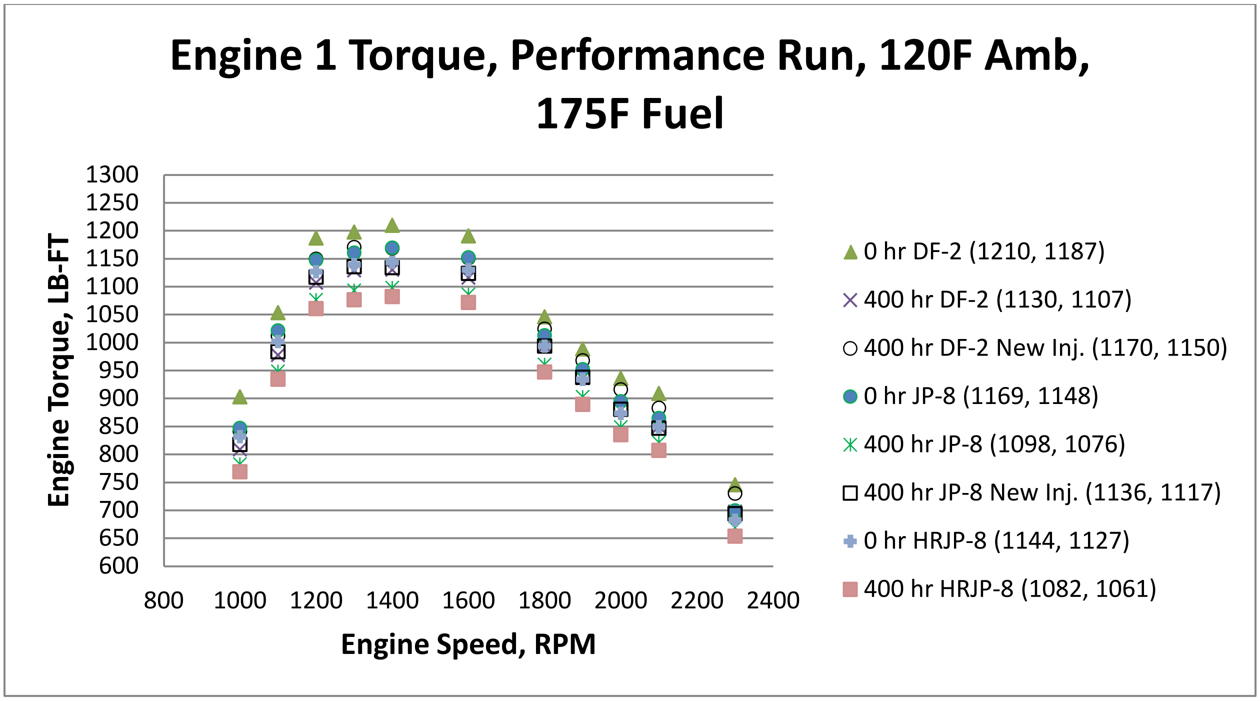


Table 1 (Standard temperature conditions, VED = Volumetric Energy Density)

Standard ambient conditions 400 Hr Energy Difference		
Fuel Type	Rated Power, Hp	VED (MJ/L)
HRJP-8	333.6	33.8
JP-8	339.6	34.6
DF-2	349.8	35.8
Fuel Type	Fuel Flow	VED
HRJP-8	117.3	33.8
JP-8	119.5	34.6
DF-2	126.0	35.8
Between	Power % diff	VED % diff
HRJP-8 & JP-8	1.81	2.30
HRJP-8 & DF-2	4.85	5.77
JP-8 & DF-2	2.99	3.40
Between	Fuel Flow % diff	VED % diff
HRJP-8 & JP-8	1.84	2.30
HRJP-8 & DF-2	7.46	5.77
JP-8 & DF-2	5.52	3.40

After New Injectors Were Installed		
Standard ambient conditions 400 Hr Energy Difference		
Fuel Type	Rated Power, Hp	VED (MJ/L)
JP-8	356.0	34.6
DF-2	366.5	35.8
Fuel Type	Fuel Flow	VED
JP-8	126.6	34.6
DF-2	131.3	35.8
Between	Power % diff	VED % diff
JP-8 & DF-2	2.95	3.40
Between	Fuel Flow % diff	VED % diff
JP-8 & DF-2	3.77	3.40

Table 2 (Elevated temperature conditions, VED = Volumetric Energy Density)

Elevated conditions 400 Hr Energy Difference		
Fuel Type	Rated Power, Hp	VED (MJ/L)
HRJP-8	318.0	32.2
JP-8	323.1	33.1
DF-2	334.7	34.3
Fuel Type	Fuel Flow	VED
HRJP-8	113.6	32.2
JP-8	116.8	33.1
DF-2	122.4	34.3
Between	Power % diff	VED % diff
HRJP-8 & JP-8	1.62	2.55
HRJP-8 & DF-2	5.27	6.37
JP-8 & DF-2	3.60	3.72
Between	Fuel Flow % diff	VED % diff
HRJP-8 & JP-8	2.82	2.55
HRJP-8 & DF-2	7.76	6.37
JP-8 & DF-2	4.80	3.72

After New Injectors Were Installed		
Elevated conditions 400 Hr Energy Difference		
Fuel Type	Rated Power, Hp	VED (MJ/L)
JP-8	335.2	33.1
DF-2	348.7	34.3
Fuel Type	Fuel Flow	VED
JP-8	120.3	33.1
DF-2	127.4	34.3
Between	Power % diff	VED % diff
JP-8 & DF-2	4.02	3.72
Between	Fuel Flow % diff	VED % diff
JP-8 & DF-2	5.95	3.72

9.2 PERFORMANCE EVALUATION USING HRJP-8 FUEL – ENGINE #2

All data are presented as observed without correction. Test conditions are described as follows: Prior (0 hrs) and post (400 hrs) test full load data sweeps were conducted for standard fuel (86ºF) and ambient air (77ºF) conditions and elevated desert operating conditions (DOC) of 175ºF and 120ºF for fuel and ambient air, respectively. These performance runs are documented in full load power vs. engine speed graphs shown in Figs. 13-14. The legends in the figures show two numbers in parenthesis next to each item. The first number is the true maximum value from the data regardless of engine rpm while the second number is the value at rated speed, 2,000 rpm for rated power and fuel flow and the values for torque and BSFC are at 1,200 rpm, which is the engine's rated torque rpm. These values will be discussed in the following discussion.

Engine #2 – True maximum values regardless of engine rpm:
Full load rated power under standard NATO conditions (86ºF fuel and 77ºF ambient air – Fig. 13) for HRJP-8 fuel at the pre 0 and post 400 hr intervals indicated 360 and 338 bhp, respectively. This represents a power decrease of 6.1%. However, when the same comparison is made between pre 0 and post 400 hr intervals using the data set for new fuel injectors at post 400 hours, the data indicates 360 and 350 bhp, respectively. This represents a power decrease of only 2.8%. This relatively small decrease over time with the new fuel injectors indicates that the majority of the 6.1% loss in the earlier comparison is due to the functional degradation of the

original fuel injectors. Full load rated power under elevated DOC conditions (175ºF fuel and 120ºF ambient air – Fig. 14) for HRJP-8 fuel at the pre 0 and post 400 hr intervals indicated 345 and 317 bhp, respectively. This represents a power decrease of 8.1% at the end of the test. When the same comparison is made between pre 0 and post 400 hr intervals using the data set for new fuel injectors at post 400 hours, the data indicates 345 and 330 bhp, respectively. This represents a power decrease of 4.3%. This full load power output decrease over time with new fuel injectors indicates that the majority of the 8.1% loss in the earlier comparison is due to the functional degradation of the original fuel injectors. Since passing the 400 hr NATO Endurance Test requires the engine to produce at least 95% of its rated power after 400 hrs, the resulting power decrease for engine #2 indicates a successful completion while operating on HRJP-8 fuel at standard and DOC conditions only if the fuel injectors are replaced at post 400 hours. Additionally, the baseline engine's rated power measured at 338 bhp after 400 hrs for standard NATO conditions, on HRJP-8 fuel, is 90.1% of its advertised 375 bhp (DF-2) rating. With new injectors installed at post 400 hours, the engine developed 350 bhp on JP-8 fuel, which represents 93.3% of its advertised 375 bhp (DF-2) rating. Therefore, the functional degradation of the factory installed injectors after operating for over 400 engine test hours accounts for the major loss in power and could ultimately determine if this particular engine would be able to pass a 400 hr NATO style endurance test when operating on HRJP-8 fuel.

Engine #2 - Values at rated power (2,000rpm) and rated torque (1,200rpm):
Full load rated power under standard NATO conditions (86ºF fuel and 77ºF ambient air – Fig. 13) for HRJP-8 fuel at the pre 0 and post 400 hr intervals indicated 353 and 331 bhp, respectively. This represents a power decrease of 6.2%. However, when the same comparison is made between pre 0 and post 400 hr intervals using the data set for new fuel injectors at post 400 hours, the data indicates 353 and 346 bhp, respectively. This represents a power decrease of only 2.0%. This relatively small decrease over time with the new fuel injectors indicates that the majority of the 6.2% loss in the earlier comparison is due to the functional degradation of the original fuel injectors. Full load rated power under elevated DOC conditions (175ºF fuel and 120ºF ambient air – Fig. 14) for HRJP-8 fuel at the pre 0 and post 400 hr intervals indicated 333 and 312 bhp, respectively. This represents a power decrease of 6.3% at the end of the test. When the same comparison is made between pre 0 and post 400 hr intervals using the data set for new fuel injectors at post 400 hours, the data indicates 333 and 327 bhp, respectively. This represents a power decrease of 1.8%. This full load power output decrease over time with new fuel injectors indicates that the majority of the 6.3% loss in the earlier comparison is due to the functional degradation of the original fuel injectors. Since passing the 400 hr NATO Endurance Test requires the engine to produce at least 95% of its rated power after 400 hrs, the resulting power decrease for engine #2 indicates a successful completion while operating on HRJP-8 fuel at standard and DOC conditions only if the fuel injectors are replaced at post 400 hours. Additionally, the baseline engine's rated power measured at 331 bhp after 400 hrs for standard NATO conditions, on HRJP-8 fuel, is 88.3% of its advertised 375 bhp (DF-2) rating. With new

injectors installed at post 400 hours, the engine developed 346 bhp on JP-8 fuel, which represents 92.3% of its advertised 375 bhp (DF-2) rating. Therefore, the functional degradation of the factory installed injectors after operating for over 400 engine test hours accounts for the major loss in power and could ultimately determine if this particular engine would be able to pass a 400 hr NATO style endurance test when operating on HRJP-8 fuel.

The full load BSFC values for standard NATO and elevated NATO (DOC) testing conditions are presented in Figs. 15 and 16, respectively. With the exception of some portions of a curve just crossing over another curve due to reading errors in the mass weigh beaker system, the BSFC values are representative and consistent with expected numbers for this engine operating on the fuels indicated.

The full load fuel consumption rate for standard and elevated (DOC) NATO testing conditions are presented in Figs. 17 and 18, respectively. The graphs show the fuel consumption rate increasing with engine speed at the expected rate of change.

The full load engine torque for standard and elevated NATO conditions are presented in Figs. 19 and 20, respectively. These figures show torque versus speed curves which are following expected trends similar to the power curves.

The charts for the energy difference at standard and elevated temperatures after 400 hours show good trends when comparing power and fuel volumetric energy differences. Tables 3 and 4 (for standard and DOC, respectively) show that the energy difference between HRJP-8 and JP-8 fuel varied by 3.49 to 3.78 percent, but the variation is hard to quantify because the uncertainties with some of the instrumentation also vary as much as 2 to 3 percent. The power data shows to have varied by slightly less than 3 percent, but the variation in power and energy difference between the two fuels are very small. The data does show that there is a small decrease in power from JP-8 to the HRJP-8 fuel, and this is a result from the energy difference in the blended fuel being lower than that of the JP-8 fuel.

Figure 13

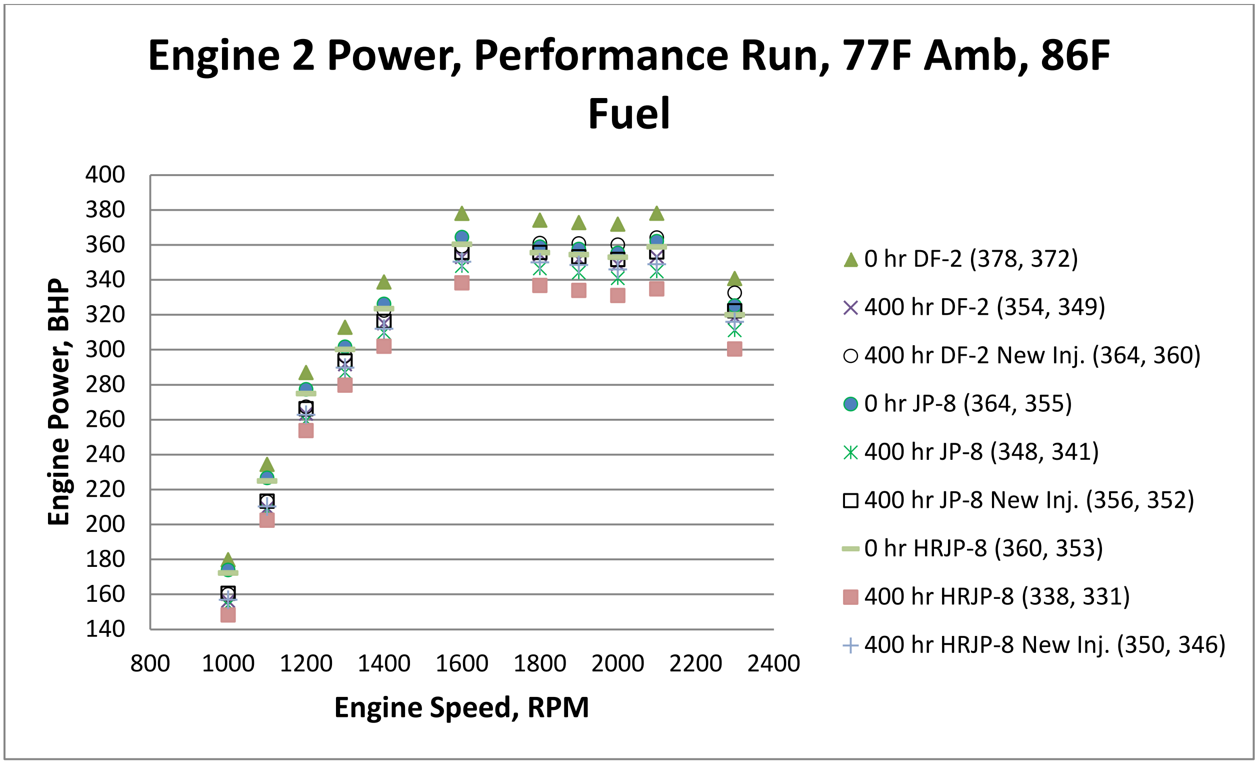


Figure 14

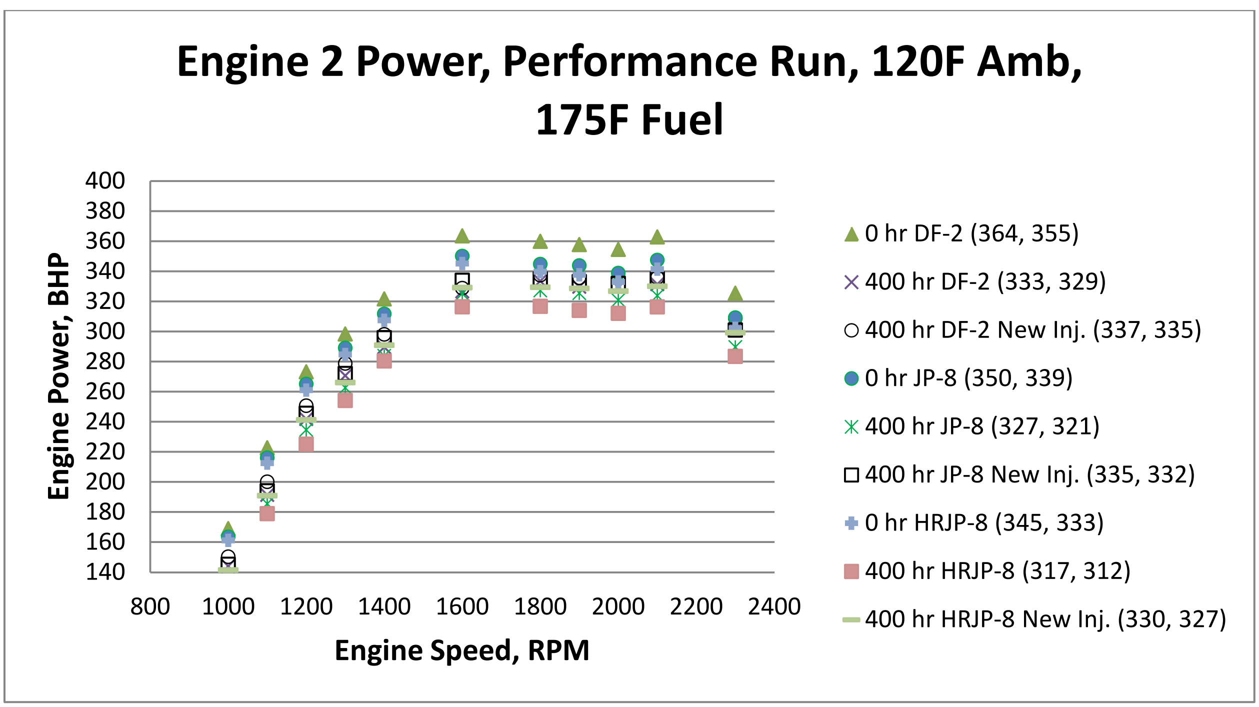


Figure 15

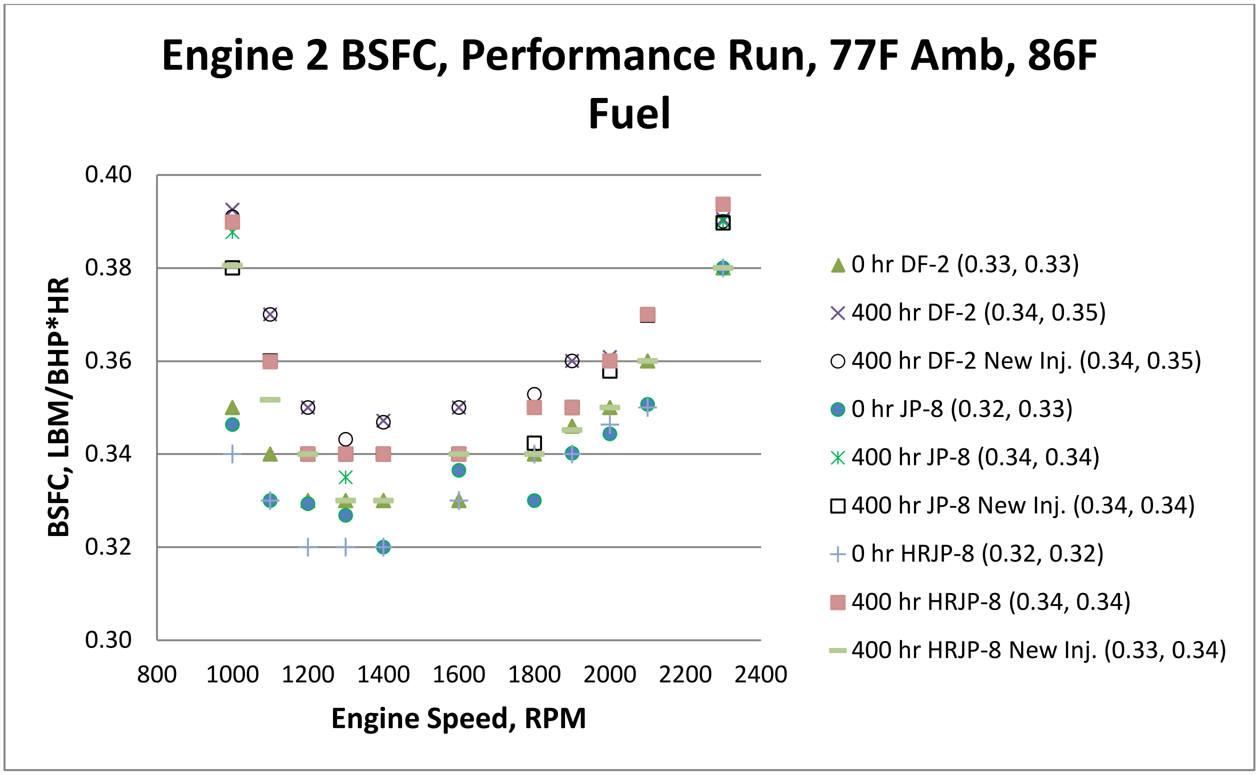


Figure 16

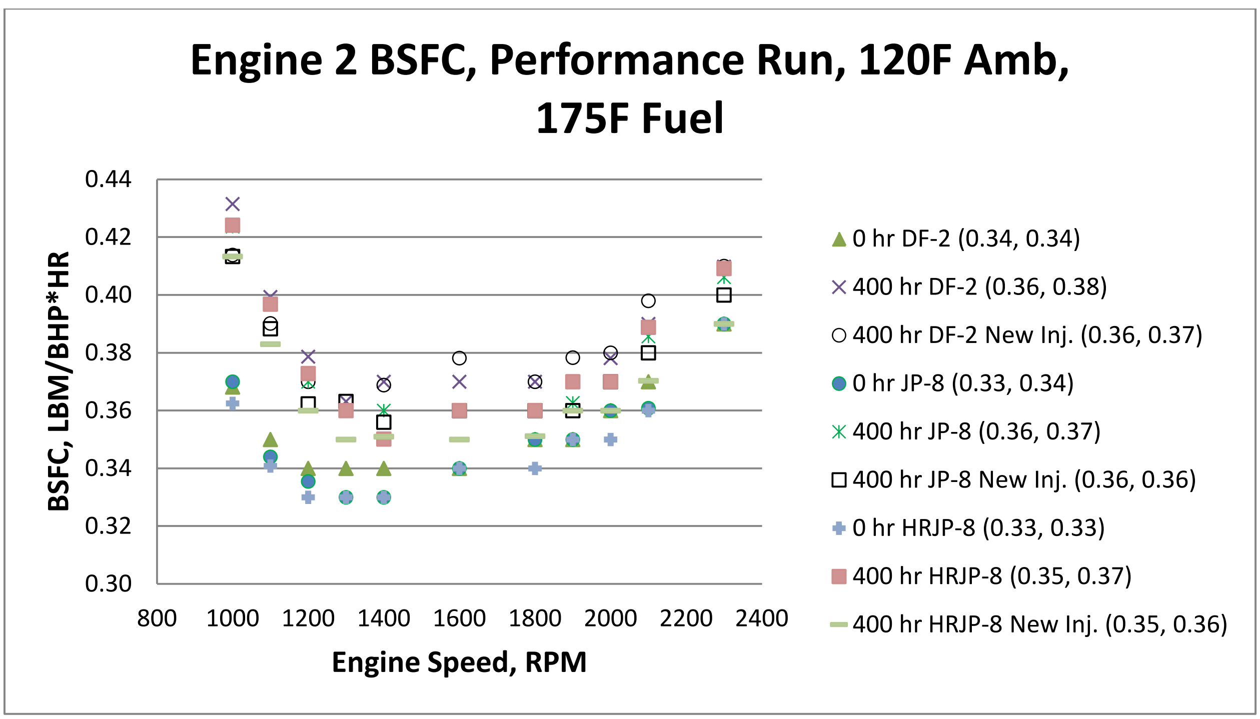


Figure 17

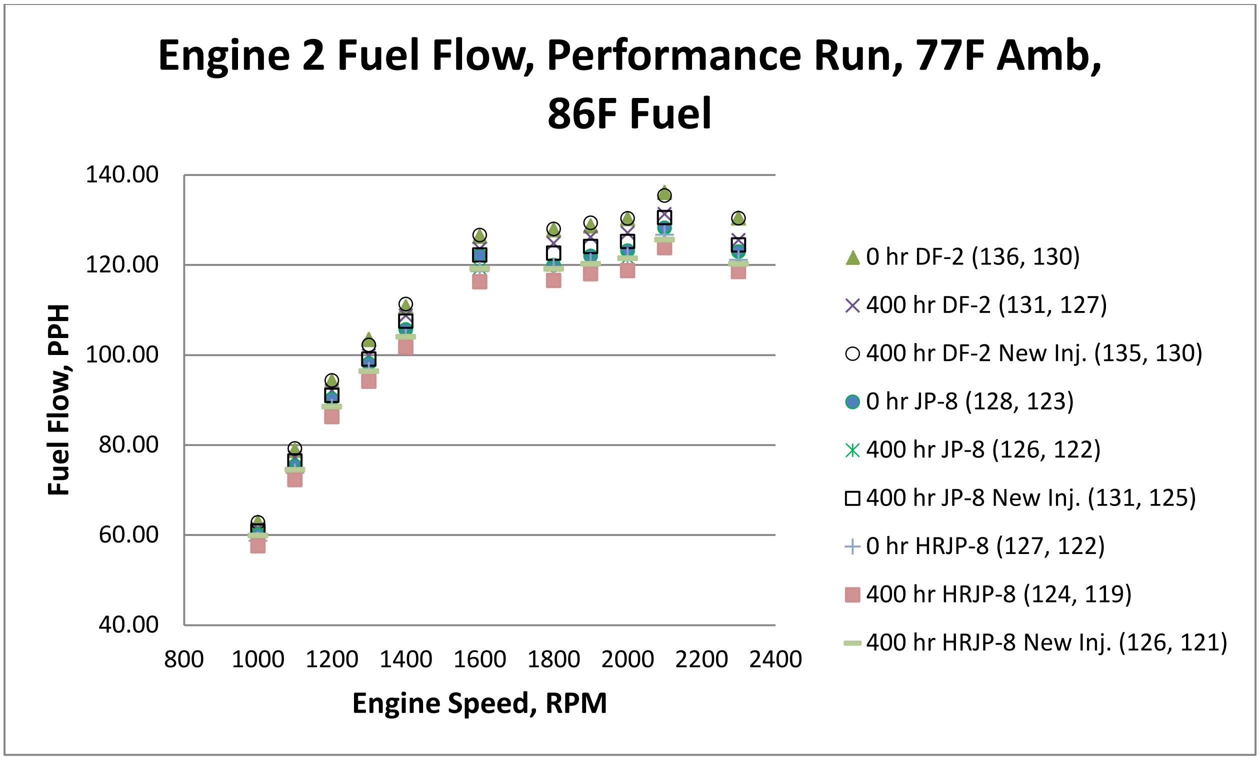


Figure 18

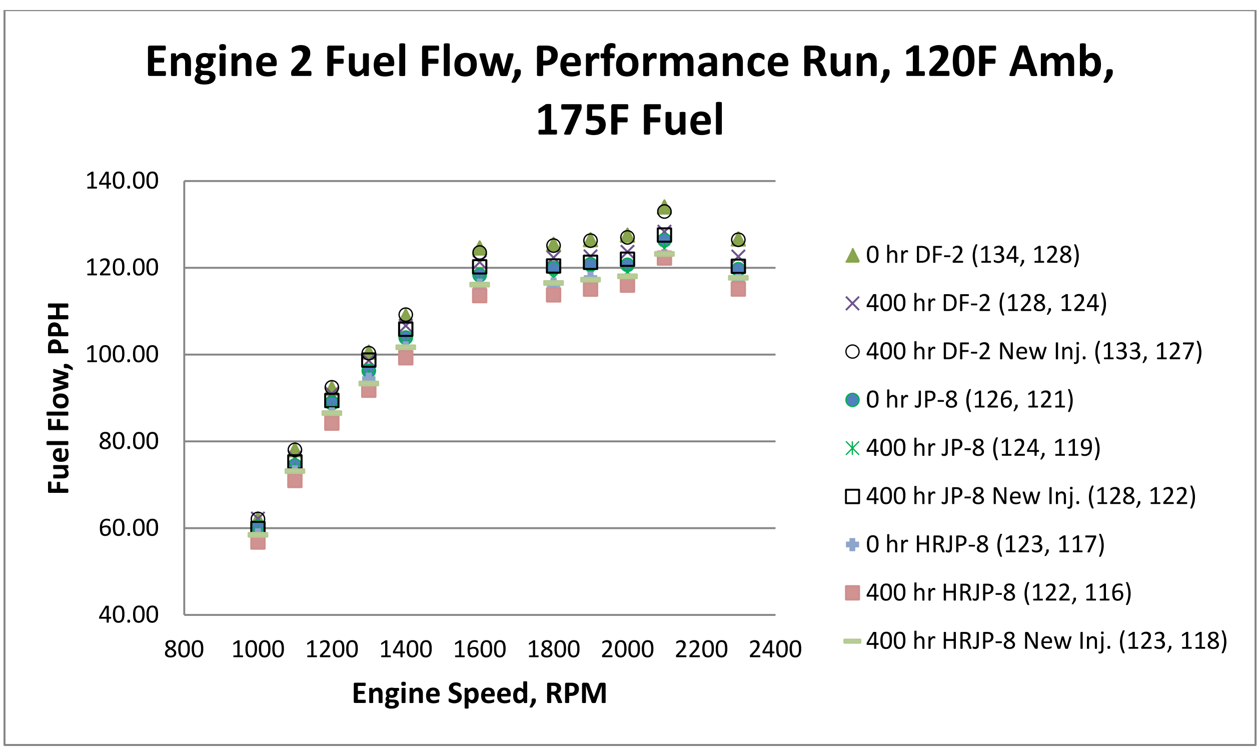


Figure 19

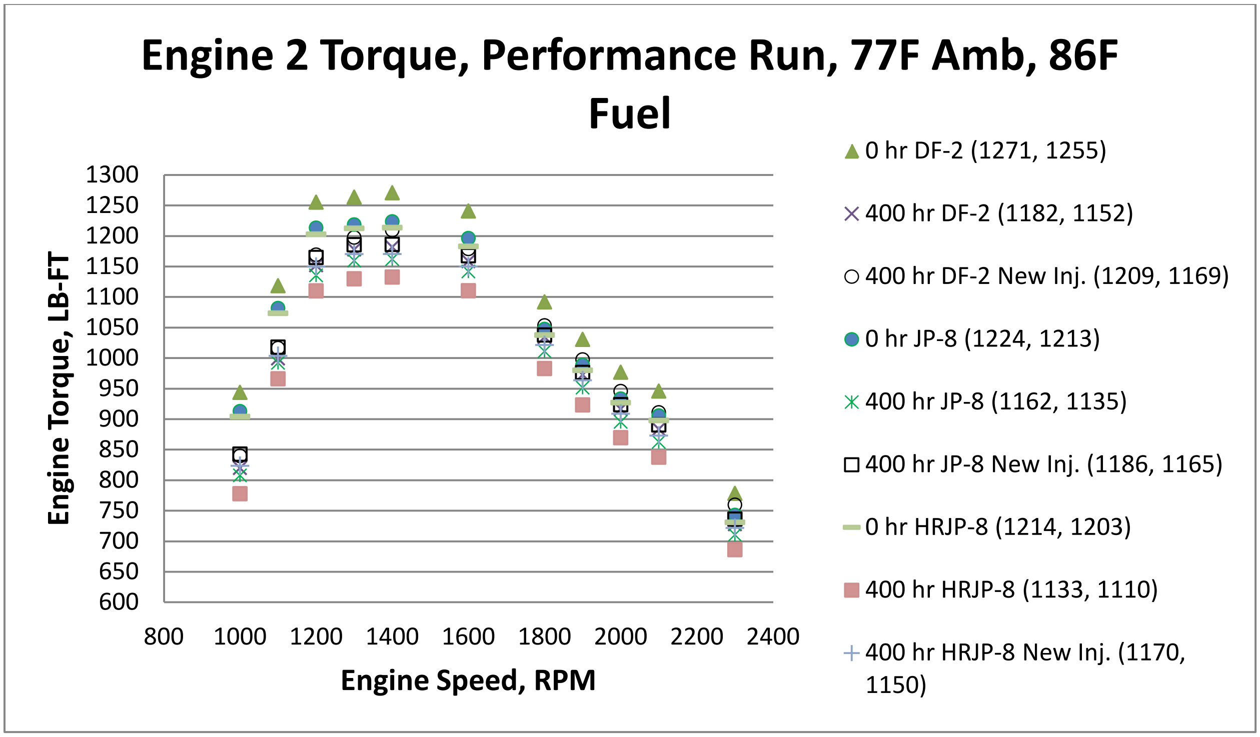


Figure 20

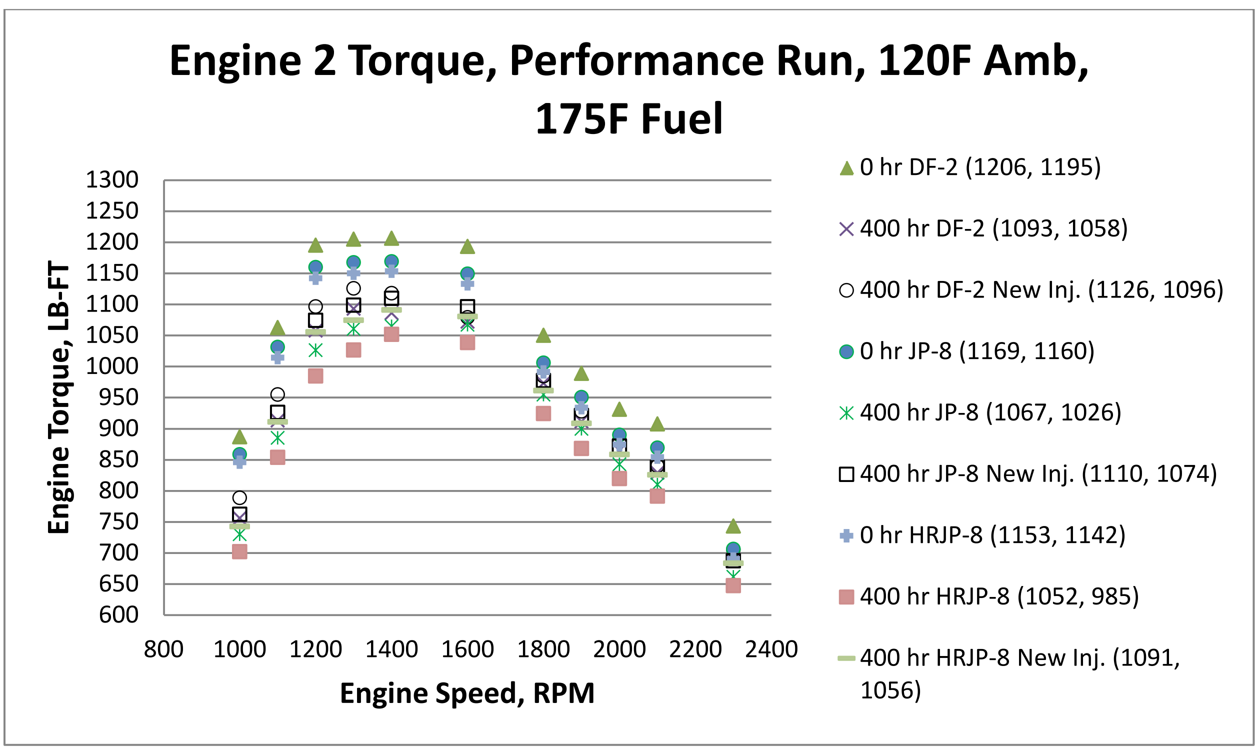


Table 3 (Standard temperature conditions, VED = Volumetric Energy Density)

Standard ambient conditions 400 Hr Energy Difference		
Fuel Type	Rated Power, Hp	VED (MJ/L)
HRJP-8	331.0	33.6
JP-8	340.9	34.8
DF-2	348.9	36.1
Fuel Type	Fuel Flow	VED
HRJP-8	118.7	33.6
JP-8	121.6	34.8
DF-2	127.1	36.1
Between	Power % diff	VED % diff
HRJP-8 & JP-8	2.98	3.49
HRJP-8 & DF-2	5.41	7.20
JP-8 & DF-2	2.36	3.58
Between	Fuel Flow % diff	VED % diff
HRJP-8 & JP-8	2.40	3.49
HRJP-8 & DF-2	7.06	7.20
JP-8 & DF-2	4.55	3.58

After New Injectors Were Installed		
Standard ambient conditions 400 Hr Energy Difference		
Fuel Type	Rated Power, Hp	VED (MJ/L)
HRJP-8	345.9	33.6
JP-8	351.6	34.8
DF-2	360.0	36.1
Fuel Type	Fuel Flow	VED
HRJP-8	121.5	33.6
JP-8	125.2	34.8
DF-2	130.3	36.1
Between	Power % diff	VED % diff
HRJP-8 & JP-8	1.64	3.49
HRJP-8 & DF-2	4.08	7.20
JP-8 & DF-2	2.39	3.58
Between	Fuel Flow % diff	VED % diff
HRJP-8 & JP-8	3.06	3.49
HRJP-8 & DF-2	7.29	7.20
JP-8 & DF-2	4.10	3.58

Table 4 (Elevated temperature conditions, VED = Volumetric Energy Density)

Elevated conditions 400 Hr Energy Difference		
Fuel Type	Rated Power, Hp	VED (MJ/L)
HRJP-8	312.0	32.0
JP-8	320.8	33.3
DF-2	329.3	34.6
Fuel Type	Fuel Flow	VED
HRJP-8	116.0	32.0
JP-8	119.1	33.3
DF-2	123.7	34.6
Between	Power % diff	VED % diff
HRJP-8 & JP-8	2.80	3.78
HRJP-8 & DF-2	5.52	7.89
JP-8 & DF-2	2.65	3.96
Between	Fuel Flow % diff	VED % diff
HRJP-8 & JP-8	2.65	3.78
HRJP-8 & DF-2	6.61	7.89
JP-8 & DF-2	3.86	3.96

After New Injectors Were Installed		
Elevated conditions 400 Hr Energy Difference		
Fuel Type	Rated Power, Hp	VED (MJ/L)
HRJP-8	326.8	32.0
JP-8	331.9	33.3
DF-2	335.4	34.6
Fuel Type	Fuel Flow	VED
HRJP-8	118.1	32.0
JP-8	122.0	33.3
DF-2	127.0	34.6
Between	Power % diff	VED % diff
HRJP-8 & JP-8	1.55	3.78
HRJP-8 & DF-2	2.64	7.89
JP-8 & DF-2	1.07	3.96
Between	Fuel Flow % diff	VED % diff
HRJP-8 & JP-8	3.34	3.78
HRJP-8 & DF-2	7.60	7.89
JP-8 & DF-2	4.12	3.96

10.0 OIL ANALYSIS

After each 100 hour oil change and maintenance the power curve revealed an increase in rated horsepower for both engines when compared to the same conditions with used oil before the oil change. The decrease in performance with used oil previously run is attributed to the engine's shearing affect on the oil over time. This shearing effect decreases the viscosity of the oil reducing the fuel injector output volume delivered to the engine.

11.0 ENGINE TEAR-DOWN:

An engine tear-down following completion of each endurance test was conducted on engine #1 and engine #2. A Navistar field engineer, very familiar with the MaxxForce 9.3L engine, inspected each of the components and was present during the teardown of engine #2. The Navistar field engineer explained to the test technician, test engineer, and customer that on some of their earlier engines problems existed with valve guides wearing down prematurely, creating high blow-by values. A solution and change to the material has already been put in place. It was concluded that the excessive values in blow-by and crankcase pressure seen in engine #2 were due to the fact that this engine had the older valve guide material which allowed the valves to develop a loose fit over the duration of this test leading to blow-by in the valve cover area. The valves were loose enough to start hitting the top surface of the pistons as shown in figure 21. A worn out valve guide from Engine #2 with the older material is shown in figure 22.

Figure 21

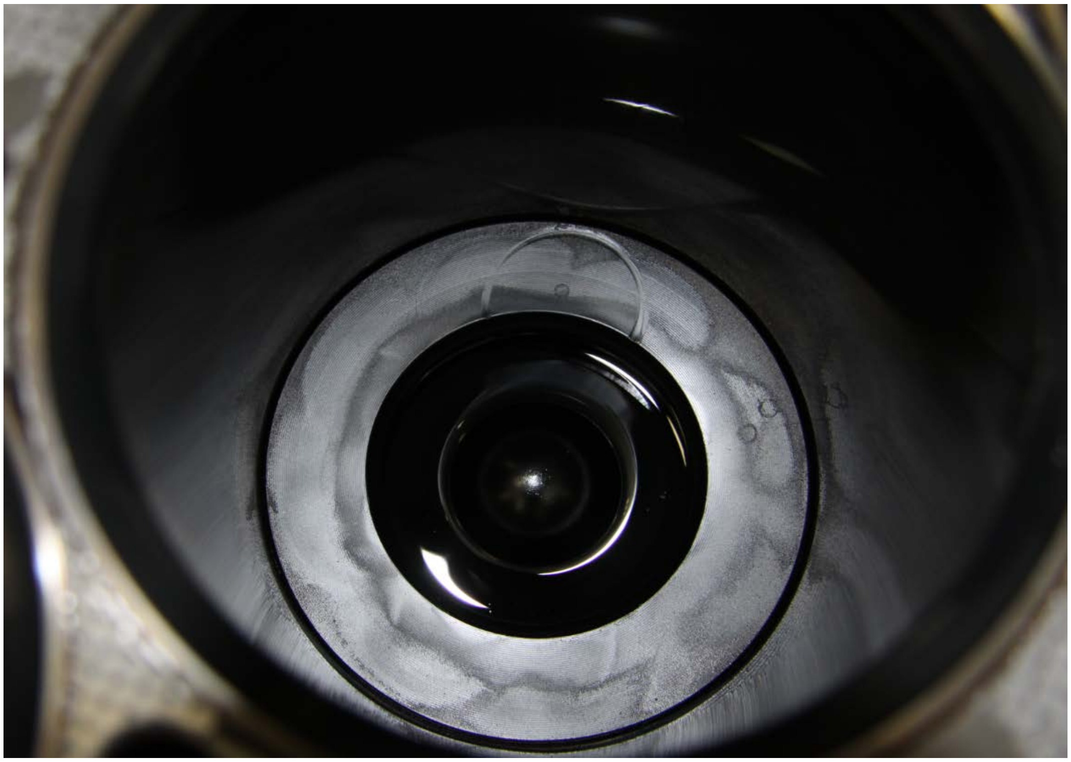


Figure 22

12.0 PUMP AND FUEL INJECTOR ANALYSIS:

After reviewing the fuel flow data, Navistar determined it was unnecessary to analyze the pump and fuel injectors since the data showed a consistent decrease in flow when comparing the fuels over the 400 hour test.

Appendix 1

Test Plan

Test Plan

Navistar MaxxForce D10 Engine Fuel Test

US ARMY TARDEC – GROUND VEHICLE POWER AND MOBILITY

TEST PLAN.v1_g

NAVISTAR MAXXFORCE D10/9.3L I-6 DIESEL ENGINE

COMPARISON TESTING OF JP-8 vs. SYNTHETIC JP-8 BLEND (HRJ)

NATO 400 HOUR DURABILITY TEST CYCLE AT DESERT OPERATING CONDITIONS

By: Matthew M. Hanselman Created: 12/20/2010, Revised: 01/31/2011

1.0 BACKGROUND

In an effort to comply with US Army Regulation 70-12, Fuels and Lubricants Standardization Policy for Equipment Design, Operation and Logistic Support, the US Army TARDEC GVPM and NAC have taken the responsibility to test and evaluate synthetic (non-petroleum crude) based fuel usage in Jet and Diesel engines. Ultimately, results from this testing will be used to determine the suitability of blending synthetic derived fuels with petroleum kerosene fuels such as JET-A and Jet Propellant-8 (JP-8). Previous diesel engine testing has been performed at TARDEC with a Fischer-Tropsch (FT) synthesis manufacturing process yielding a Synthetic Paraffinic Kerosene (SPK). This testing described in this plan will also be on an SPK fuel; however, it is derived from a different manufacturing process called hydro-treatment, thus yielding Hydro-processed Renewable Jet (HRJ) fuel. The HRJ fuel being tested will be delivered for testing as a prescription 50/50 blend (vol.) meeting Military Spec. JP-8 (MIL-DTL-83133G). For the remainder of this document it will be referred to as *"HRJP-8"*.

2.0 OBJECTIVE

The purpose of this testing is to quantitatively measure any changes in engine performance, durability or operating characteristic as compared to straight JP-8 and to also better understand the overall durability of the subject engine. The engine to be used in this testing is a Navistar Inc. MAXXFORCE D10/9.3L I-6 used to power the Navistar MRAP military vehicle. The test procedure and cycle is a modified version of the NATO Document AEP-5 Ver. 3 (aka NATO 400 Hour Durability). Modifications to this procedure are primarily increases to the operating temperatures of the engine coolant, combustion air and fuel supply to extremes seen during actual vehicle usage called Desert Operating Conditions (DOC). The focus will be on the engines entire fuel system. This consists of the fuel delivery system (lines, filter and low pressure pump), seals and fuel injectors (hydraulically-actuated unit type). *Strict adherence to the pass/fail criteria of the NATO AEP-5 will not be followed since the focus of this testing is on identifying performance similarities and differences between DF-2, JP-8 and HRJP-8 as well as gathering general engine durability information.*

The first engine will perform a durability cycle on JP-8 and the second engine will follow performing a durability cycle on the HRJP-8. Prior to the start of the durability cycle, each engine will perform a break-in procedure and full load performance evaluations to baseline performance on DF-2, JP-8 and HRJP-8 fuels at both standard NATO AEP-5 and the modified DOC temperatures. If sufficient amounts of residual Fischer-Tropsch blended JP-8 (FTJP-8) is available in barrels from previous testing, it is possible that baseline performance testing will be accomplished.

3.0 TEST SET-UP AND GUIDELINES

Navistar Engine Group (Division of Navistar Inc.) has agreed to lend TARDEC-NAC some test equipment and engine parts that aid in the set-up and testing of the two engines. These parts and equipment have been inventoried and will be return following the completion of testing. Below is a list of guidelines for installation and set-up.

1. Install the engine in test cell #1 using the best practices developed by TARDEC GVPM with the parts specified in the "*GVPM Test Record Notebook"*.

2. Install the test equipment, controllers, materials and instrumentation specified in the "*GVPM Test Record Notebook and Navistar MAXXFORCE D10 Reference Material Notebook"*.
3. Test measurements and data acquisition will be standard GVPM specification *plus* any additional requirements specified by the GVPM test engineer and the customer.
4. Test fire the engine on JP-8 fuel and exercise the engine, dynamometer, control equipment and instrumentation through the full operating range and verify proper function.
5. Calibration of the cell controllers to ensure the ability to quickly achieve normal and DOC bogeys.
6. Calibration of the dynamometer load cell and verify repeatable precision and accuracy.
7. Verify data acquisition is recorded at the required points and of frequency (Hz) required by the customer.
8. Prior to the start of the cycle, each engine will run a break-in procedure recommended by Navistar in accordance with the NATO AEP-5 procedure.
9. Engine maintenance will be performed at 100 hr intervals (see section 4.4.2 for details).
10. Engine baseline performance procedures will be done at 100 hr intervals (See section 4.2 for more detailed information).
11. Engine oil samples will be taken at 0 hrs (after the initial performance evaluation procedure) and at 100 hr test cycle intervals thereafter. Samples will be taken at the end of a daily 10 hr cycle while the engine is fully warmed. The 0, 100, 200, 300 and 400 hr samples will be analyzed by the TARDEC Fuels and Lubricants Dept. Oil samples will be 250 ml in size. Refer to Attachments A & B for additional information.
12. Engine oil is MIL Spec. SAE 15W-40 supplied in 2-55gal drums manufactured from the same lot.
13. Fuel samples will be taken on a need basis when new deliveries are made or tanks mixtures change and will be analyzed by the TARDEC Fuels and Lubricants Dept. Fuel samples will be at least 1 US gal size in a metal can provided by the TARDEC Fuels and Lubricants Dept. Refer to Attachment C for further guidance.
14. Engine coolant is ethylene glycol "FLEET CHARGE" in 50/50 mixture with city water.
15. Fuel changes will be performed according to the best practices of TARDEC GVPM during the baseline performance procedures. The following may be performed if deemed necessary to reduce blended fuel waste: Fuel lines will be disconnected as close to the engine as possible and fuel will be purged (wasted) from the supply and return lines, fuel heater and mass flow scale. The fuel filter will be removed, purged and reinstalled.

4.0 ENGINE BREAK-IN, PERFORMANCE BASELINE, NATO AEP-5 ver. 3 DURABILITY TEST PROCEDURES AND MAINTENANCE

4.1 BREAK-IN

Each engine will run break-in on DF-2 fuel and operate at Normal conditions. The break-in cycle is the recommendation by Navistar Engine Group in accordance with the NATO AEP-5 procedure and is described below in Table 1A and 1B.

TABLE 1A

$Time_1$ (min)	$Time_2$ (min)	N (RPM)	Load (Ft-Lbs)
0	5	800	200
5	10	800	400
10	15	800	600
15	20	1000	400
20	25	1000	600
25	30	1000	800
30	35	1400	600
35	40	1400	800
40	45	1800	800
45	50	1800	1100
50	55	2200	500
55	60	2200	700

TABLE 1B

Time$_1$ (hr)	**Time$_2$ (hr)**	**N (RPM)**	**Load (Ft-Lbs)**
0	5	2000$_{RATED}$	FULL

4.2 BASELINE PERFORMANCE CHARACTERIZATION TEST

Baseline performance testing will be conducted on four (4) different fuels at Normal and DOC conditions in series according to the following matrix below prior to the start of the NATO AEP-5 Durability cycle. Test points for engine speed and load are described below. The scheme for Table 2 will be repeated for each fuel in the following order, DF-2, JP-8, FTJP-8 & HRJP-8. Data acquisition shall be at least 1 Hz for 60 seconds at the end of each test point. Test point duration may need to differ from the values in Table 2 depending on the time required to stabilize.

TABLE 2

Fuel	**Duration (min)**	**Conditions**	**N (RPM)**	**Load**
DF-2	TBD (______)	Start / Warm-up	TBD (______)	TBD (______)
	6:00	Normal	2300	FULL
			2100	
			2000	
			1900	
			1800	
			1600	
			1400	
			1300	
			1200	
			1100	
			1000	
			800	
		DOC	2300	
			2100	
			2000	
			1900	
			1800	
			1600	
			1400	
			1300	
			1200	
			1100	
			1000	
			800	

Repeat Table 2 for JP-8, FTJP-8 & HRJP-8 fuels.

4.3 NATO AEP-5 DURABILITY CYCLE TESTING (400 Hours)

The durability cycle will begin at the completion of the baseline performance procedure. The first test engine will run on JP-8, the second will run on HRJP-8. Table 3 below describes the cycle test points and duration. The engines will be run at Desert Operating Conditions (DOC) described in Section 10.0, Table 4.

TABLE 3

Sub-Cycle	Rated Speed [1] %, (rpm)	Load	Sub-Cycle Duration (hrs)	Total (hrs)
1	Idle, (800)	0%	0.5	0.5
2	100%, (2000)	100%	2.0	2.5
3	Governed, (2300)	0 (minimum)	0.5	3
4	75%, (1500)	100%	1.0	4
5	Idle, (800) … step to … 100%, (2000), repeat 11X.	0% (4min)… step to … 100% (6min), repeat 11X.	2.0	6
6	60% (1200)	100%	0.5	6.5
7	Idle, (800)	0%	0.5	7
8	Governed, (2300)	70%^{MEAS} (_490_ Ft-Lbs)	0.5	7.5
9	Max Torque Speed, (1200)	100%	2.0	9.5
10	60%, (1200)	50% ^{MEAS} (_575_ Ft-Lbs)	0.5	10

[1] Rated Speed is 2000 rpm

%^{MEAS} % of measured load from initial performance test at corresponding engine speed.

4.4 PERFORMANCE CHARACTERIZATION TESTING AND MAINTENANCE

4.4.1 PERFORMANCE CHARACTERIZATION TESTING

Performance characterization testing will occur at the end of each 100 Hr durability interval before all maintenance is performed described in Section 4.4.2. The test point and scheme is described in Table 2 of Section 4.2 at Normal and DOC conditions. Per NATO AEP-5, if the engine performance falls below 95% as compared to the baseline levels determined prior to the start of the durability test cycle, normal maintenance can be performed before re-testing. If repeat testing results still fall below 95%, the test cycle will be stopped until further review with the customer.

Immediately following the "*on*" cycle fuel type performance characterization testing, the "*off*" cycle fuel type(s) performance testing will be completed for as many types of fuel (ie. DF-2, others) that are available or at the request of the customer.

4.4.2 MAINTENANCE

Normal scheduled maintenance will begin with an oil and oil filter change at initial engine installation. The oil and oil filter will be changed again following the end of the break-in procedure prior to the start of the initial full load performance characterization testing. Oil and oil filter changes will then occur at regular 100 hr durability cycle intervals following the performance characterization tests. Fuel filter changes will occur at the same time as the oil filter changes. Air filter changes will only occur if necessary to maintain a pressure delta across the filter element per NATO AEP-5 specifications. Record oil sampling in

Attachment B and also in the "*GVPM Test Record Notebook*". Engine oil fill capacity is 13.0 qts. US (wet) including filter.

5.0 END OF DURABILITY CYCLE
At the completion of the full 400 hour cycle, normal maintenance will be performed followed immediately by baseline performance characterizations described in Table 2 of Section 4.2 will be performed. Testing will be at both normal and DOC conditions and repeated for each type of fuel available (DF-2 JP8, HRJP-8 & FTJP-8).

6.0 DATA REVIEWS
Data reviews will occur with the customer periodically immediately after completion of major milestones in the testing. The following are suggested:

A. Break-in.
B. Baseline performance characterization of Section 4.2.
C. 100 hour cycle intervals.
D. End of durability cycle baseline performance characterization of Section 4.2.
E. Follow-on testing.

7.0 FOLLOW-ON TESTING
No follow-on testing has been determined at this time. Additional testing will be at the discretion of the customer and the availability of the GVPM test facility.

8.0 TEARDOWN, INSPECTION AND DISPOSAL
Upon completion of the durability cycle testing or any follow-on testing, the engines will be removed and disassembled for inspection. Standard GVPM inspection and documentation will be performed. Disposal of the test articles will be at the discretion of the customer. Borrowed equipment shall be returned to Navistar Engine Group within 90 days of completion of all testing.

9.0 TECHNICAL REPORT
A report will be written by a GVPM test engineer summarizing the performance of each test article (engine) and the condition it was tested under using standard GVPM reporting methods. The report will include data analysis and conclusions about the similarities and/or differences between JP-8 and the HRJP-8 blend. The report will be submitted to the customer for final approval. Test results will be publicized at the discretion of the customer.

10.0 NORMAL AND DESERT OPERATING CONDITION DESCRIPTION
Table 4 below describes the target set points for several engine operating parameters for both NATO AEP-5 Normal and for the TARDEC-GVPM derived desert operating conditions (DOC). The DOC points are considered to be worst case scenario and were chosen based on manufacturer information and the observation and experience of TARDEC-GVPM subject matter experts.

TABLE 4

	Target Set Point	
Engine Operating Parameters	**Normal**	**DOC**
Air Charge Inlet Temp (at Filter)	77 F +/- 5 F	120 F +/- 5 F
Charge Air Cooler Outlet Temp (Estimated)	30 F +/- 5 F over ambient	30 F +/- 5 F over ambient
Engine Coolant Outlet Temp	205 F +/- 3 F	220 F +/- 3F
Fuel Supply Temp (inlet to low pres pump)	86 F +/- 5 F	175 F +/- 5 F
Induction Air Depression	-10 +/- 2 F in-H_2O	-10 +/- 2 F in-H_2O
Exhaust Backpressure	16 +/- 2 F in-H_2O	16 +/- 2 F in-H_2O

11.0 MANUFACTURER ENGINE OPERATING LIMITS

In addition to the operating conditions described in Section 10, there are several additional engine operating parameters that should be monitored and controlled to certain levels. Operating the engine outside of these limits could cause engine damage or result in the engine operating outside of its intended design. This could include de-rated operation such as overheat protection or mechanical damage avoidance modes. Care needs to be taken to identify and stay clear of these limits during testing to maintain test integrity and avoid performance hysteresis. Table 5 below lists the manufacturer's limits.

TABLE 5

	Engine Operating Parameters	Unit	*Global		**At Rated Performance		
			Min	Max	Min	Nominal	Max
Temperature	Engine Coolant Inlet	F	200	210	--	--	--
	Engine Coolant Outlet	F	--	227	200	215	225
	Oil Gallery	F	--	--	--	--	--
	Compressor Outlet	F	--	425	320	340	360
	Intake Manifold Inlet	F	--	--	+ 30 over Ambient		
	Exhaust Collector (Before Turbine)	F	--	1350	1220	1250	1300
	Exhaust Stack (Turbine Outlet)	F	--	1130	--	1030	--
	Oil Sump	F	--	280	220	--	250
Pressure	Air Inlet Restriction	in-H_2O	18	20	--	--	24
	Crankcase	in-H_2O	--	28	--	--	28
	Exhaust Stack Restriction	in-Hg	--	--	--	--	8
	Oil Gallery	psig	20	80	55	60	70
	Fuel After Lift Pump	psig	40	--	40	--	70
	Compressor Outlet	in-Hg	--	60	45	50	60
	Charge Air Cooler Restriction	in-H_2O	52	57	--	--	--
	Intake Manifold	in-Hg	18	19	--	--	--
	Exhaust Manifold	in-Hg	--	81	55	60	70
	Fuel Supply to Engine	in-Hg	-1	1	--	--	--
Misc.	Fuel Consumption	lb_m/hr	--	155	129	135	141
	Blowby	cfh	--	750	--	--	--

* Applies to any engine operation point. Design intent range is 800 rpm (idle) to 2300 rpm (governed).
** Applies to 2000 rpm full load & SAE std. conditions (77 F ambient rated at 375 Hp).

12.0 TEST PLAN APPROVAL

TARDEC GVPM:

Approver: ____. Date: _____________________.

Mike Reid, Team Leader, GVPM, TE&A

TARDEC-NAC:

Approver: ____. Date: _____________________.

Eric Sattler, NAC

13.0 REVISION RECORD *(revisions since approval signatures in Section 12.0)*

Revision Date (MM/DD/YYYY)	**Brief Description of Change**	**Approval Initials**	
		GVPM	**NAC**
04 / 07 / 2011	Raised DOC Fuel Supply Temp set point from 165F to 175F (Table 4).	MH	
04 / 13 / 2011	Table 1A and 2, 900 rpm set point changed to 800 rpm.	MH	
04 / 13 / 2011	Added Table 3 Sub-cycles 8 & 10 load set points 490 & 575 Ft-lbs respectively.	MH	
04 / 13 / 2011	Turbo Compressor Outlet Temp increased from 375F to 425F (warning) & 450F (shutdown).	MH	
04 / 20 / 2011	Added engine oil fill capacity to section 4.4.2	MH	

ATTACHMENT A – TEST OIL MANUFACTURING INFORMATION DATA FORM

Barrels 1 & 2 (55 GL) WT 444 CU 11.0	**Record Below**	**Initial**
MIL Performance 2104H Information:	9150-01-438-6079	MH
Grade:	15W-40	
Manufacturer Identification:	SAFETY-KLEEN SYSTEMS, INC 30530 SPM4A6-09-D-0146	
Date of Manufacture:	MFD 09/10 TEST 08/13	
Lot #:	GM039/007	
Qualification #:	MC-3891	

ATTACHMENT B – OIL SAMPLE SCHEDULE & DATA FORM

TEST ENGINE 1: S/N 570HM2U3081497							
Sample #	**Sample Interval**	**Send for Analysis**	**Hold Sample in Cell**	**Sample* (Qty)**	**Performed Date (MM/DD/YYYY)**	**Initial**
1	New from Barrel (Unused)	No	Yes	1 - 250ml		
2	Post Break-in procedure	No	Yes	1 - 250ml	03 / 31 /2011	MH
3	0 Hr (Post Performance Evaluation)	Yes	Yes	2 - 250ml		
4	100 Hr Cycle Mark	Yes	Yes	2 - 250ml		
5	200 Hr Cycle Mark	Yes	Yes	2 - 250ml		
6	300 Hr Cycle Mark	Yes	Yes	2 - 250ml		
7	400 Hr Cycle Mark	Yes	Yes	2 - 250ml		
TEST ENGINE 2: S/N 570HM2U3065168						
Sample #	**Sample Interval**	**Send for Analysis**	**Hold Sample in Cell**	**Sample* (Qty)**	**Performed Date (MM/DD/YYYY)**	**Initial**
1	New from Barrel (Unused)	No	Yes	1 - 250ml		
2	Post Break-in procedure	No	Yes	1 - 250ml		
3	0 Hr (Post Performance Evaluation)	Yes	Yes	2 - 250ml		
4	100 Hr Cycle Mark	Yes	Yes	2 - 250ml		
5	200 Hr Cycle Mark	Yes	Yes	2 - 250ml		
6	300 Hr Cycle Mark	Yes	Yes	2 - 250ml		
7	400 Hr Cycle Mark	Yes	Yes	2 - 250ml		
* Mark samples with date & sample interval. Samples should be taken from the sump with engine hot at the end of a 10 hr cycle. Samples being held should be stored in a cool place (~70 F). Oil samples should be sent for analysis immediately (within 72 hrs). Additional samples may be taken at the request of the customer.						

ATTACHMENT C – FUEL SAMPLE SCHEDULE

Sampling Interval	Send for Analysis	Responsible Person	Sample* (Qty)	Fuel Type		
				DF-2	JP-8	Blends
Off-the-Truck**	Yes	GVPM Facility Engr	1 - 1.0 gal			X
0 Hr (Post Breakin)	Yes	Test Cell Tech/Engr	1 - 1.0 gal	X	X	X
400 Hr Cycle Mark	Yes	Test Cell Tech/Engr	1 - 1.0 gal	X	X	X
* Fuel samples to be sent for analysis immediately (within 72 hrs). Fuel sample minimum volume is 1 US gallon in an approved clean metal container. 0 & 400 hr samples will be taken at the test cell when it is determined that the sample is representative of well mixed fuel from the supply tank. When new fuel deliveries arrive, additional samples will need to be taken. ** Off-the-Truck refers to a sample taken directly from the delivery truck supply hose near the end of the fill.						

Appendix 2

Table 1. Instrumentation List

Label	Measured Data	Generic Name	Location (boom)	Units	Range	Calibration Date
		Temperature				
	Air	Air Cell Ambient		°F		
	Air	Air Comp Inlet		°F		
	Air	Air Comp Out		°F		
	Air	Air Filter Inlet		°F		
		Pressure				
	Air	Air Cell Depression		in H_2O		
	Air	Air LFE		in H_2O		
	Air	Air Comp Inlet		in H_2O		
	Air	Air Comp Out		psig		
		Temperature				
	Oil	Oil Engine Sump		°F		
		Pressure				
	Oil	Oil Gallery		psig		
		Temperature				
	Fuel	Fuel Beaker		°F		
	Fuel	Fuel Engine In		°F		
	Fuel	Fuel Return		°F		
		Pressure				
	Fuel	Fuel Return		psig		
	Fuel	Fuel Engine Supply		psig		
		Temperature				
	Water	Water Tower Out		°F		
	Water	Water CAC Outlet		°F		

	Water	Dyno Water In		°F		
	Water	Dyno Water Out		°F		
Pressure						
	Water	Pond Water		psig		
	Water	Tower Water Out		psig		
	Water	Dyno Water		psig		
Flow Rate						
	Water	Water Tower Flow		GPM		
Temperature						
Coolant	Coolant	Coolant Engine In		°F		
Coolant	Coolant	Coolant Engine Out		°F		
Pressure						
Coolant	Coolant	Coolant Engine In		psig		
Coolant	Coolant	Coolant Engine Out		psig		
Coolant	Coolant	Coolant Cap		psig		
Temperature						
Exhaust	Exhaust	Exhaust Port 1		°F		
Exhaust	Exhaust	Exhaust Port 2		°F		
Exhaust	Exhaust	Exhaust Port 3		°F		
Exhaust	Exhaust	Exhaust Port 4		°F		
Exhaust	Exhaust	Exhaust Port 5		°F		
Exhaust	Exhaust	Exhaust Port 6		°F		
Exhaust	Exhaust	Turbo Turbine Outlet		°F		
Pressure						
Exhaust	Exhaust	Exhaust Bank 1 Before Turbo		psig		
Exhaust	Exhaust	Exhaust Turbine Out		in H_2O		
Other						
Other	Crank Case			in H_2O		

Other	Blowby			cfm		
Other	Relative Humidity			%		
Other	Relative Humidity Temp			°F		
Other	Dyno Speed			rpm		
Other	Engine Torque			ft-lbs		
Other	Throttle Position			%		
Other	Brake Horsepower			BHP		
Other	Fuel Flow			lb/hr		
Other	Air Density			lbs/ft^3		
Other	Barometric Pressure			In Hg		
Other	AVL Smoke Meter			FSN		

Appendix 3

Engines #1 & #2 Sample Data

ENGINE 1 – 100 hour JP-8 Performance Run, Standard and DOC Data Summary

JP-8	100 HRS	Exhaust Port 1	Exhaust Port 2	Exhaust Port 3	Exhaust Port 4	Exhaust Port 5	Exhaust Port 6	Turbo Turbine Outlet	Air Cell Ambient	Air Filter Inlet	CAC Inlet	CAC outlet	Intake Manifold	Coolant Engine In	Coolant Engine Out	Oil Sump Temp	Fuel Beaker	Fuel Engine In
RPM	Standard	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg F	Deg f	Deg F
2300		1060.60	1077.47	1071.05	1027.18	1060.12	1011.60	832.80	75.32	75.79	343.10	111.40	107.19	184.73	196.96	240.36	69.12	88.65
2100		1092.23	1119.27	1108.13	1070.68	1101.34	1050.70	883.42	76.18	78.59	340.92	110.79	106.95	183.41	196.97	242.70	69.12	88.05
2000		1074.26	1101.93	1089.36	1046.64	1071.33	1022.15	867.05	75.95	78.87	335.12	111.21	107.41	183.36	196.94	242.69	68.17	88.23
1900		1080.48	1112.07	1098.69	1061.29	1081.27	1024.42	878.77	76.56	79.52	336.60	111.02	107.16	182.86	196.92	241.98	67.27	88.11
1800		1069.05	1100.31	1091.86	1058.21	1073.62	1023.06	868.36	76.12	79.40	341.46	111.13	106.75	182.42	196.85	241.88	66.89	88.20
1600		1085.50	1138.23	1132.76	1109.92	1124.20	1065.09	924.66	76.91	80.60	336.34	111.11	107.40	180.78	196.91	242.22	66.56	88.09
1400		1040.47	1109.74	1111.64	1091.28	1090.14	1032.24	928.55	76.85	80.10	314.57	110.99	107.96	180.16	196.89	242.30	65.99	88.31
1300		1007.86	1082.22	1087.46	1072.46	1070.62	1009.47	905.66	76.41	79.83	312.92	110.68	107.99	179.98	196.89	241.20	65.83	88.13
1200		1007.99	1089.70	1095.12	1075.67	1072.41	1004.04	919.34	77.13	79.66	302.60	111.03	108.55	179.43	196.97	241.08	66.27	88.29
1100		1022.65	1115.29	1122.03	1095.03	1087.16	1014.92	973.10	76.25	79.86	267.40	110.42	108.32	179.76	197.02	239.13	65.87	88.18
1000		1042.13	1127.75	1130.79	1100.79	1093.63	1017.52	1013.34	75.29	78.25	221.91	110.05	107.63	179.84	196.66	236.25	66.08	88.25
800		1041.89	1068.09	1047.52	1004.80	1022.83	960.49	938.16	74.28	77.54	176.37	112.94	109.00	181.07	196.78	232.45	66.01	88.00
	DOC																	
2300		1121.90	1128.89	1117.23	1085.35	1109.62	1073.40	873.05	110.61	120.43	403.66	152.03	145.63	206.37	219.53	264.37	79.92	170.98
2100		1162.31	1181.75	1164.36	1130.06	1158.40	1104.33	928.14	110.79	119.44	401.93	151.73	145.93	205.38	219.58	266.00	79.36	171.21
2000		1117.74	1143.57	1132.27	1097.85	1119.31	1066.31	895.44	111.33	121.26	400.27	151.76	146.43	205.25	219.53	265.54	78.64	172.51
1900		1130.76	1160.91	1146.16	1111.03	1135.30	1077.13	910.77	111.96	121.54	400.85	151.75	146.60	204.75	219.35	264.90	77.36	172.50
1800		1134.55	1163.90	1150.71	1120.78	1139.66	1087.22	918.82	113.05	120.25	400.26	151.87	147.04	204.17	219.33	265.05	77.05	173.28
1600		1153.88	1201.14	1191.80	1166.03	1180.95	1115.93	967.96	113.00	120.43	397.03	151.59	147.08	202.57	219.52	265.88	76.75	173.50
1400		1107.90	1173.53	1172.64	1155.31	1153.70	1085.82	979.07	113.97	120.89	374.36	151.68	147.72	201.36	219.04	266.04	79.26	173.46
1300		1083.27	1161.09	1160.07	1146.36	1145.85	1074.49	971.89	115.52	120.92	367.77	151.90	148.32	201.72	219.45	264.73	79.73	173.17
1200		1090.43	1174.00	1173.59	1154.07	1150.40	1070.44	989.43	116.62	120.03	358.23	152.01	148.22	200.69	219.17	264.48	80.57	172.65
1100		1106.00	1208.10	1207.65	1176.54	1167.97	1086.53	1057.06	116.32	121.50	317.68	152.12	148.70	200.99	219.39	261.79	80.68	171.97
1000		1117.80	1221.07	1215.75	1182.00	1173.84	1083.29	1104.78	117.38	121.33	272.20	152.13	148.38	201.64	218.99	257.71	81.56	171.61
800		1143.27	1168.75	1142.50	1076.93	1096.18	1031.41	1023.08	116.55	122.35	230.86	152.00	146.91	202.52	219.05	252.84	81.58	170.49

JP-8	100 HRS	Air LFE	Intake Manifold	CAC Delta P	Exhaust Bank 1 B4 Turbo	Exhaust Turbine Out	Crankcase	Oil Gallery	Fuel Engine Supply	Coolant Engine In	Coolant Engine Out	Dyno Speed	Dyno Torque	Throttle Position	Blowby	BSFC	BHP	Mass Fuel Flow
RPM	Standard	H2O	Psig	Psig	Psig	H2O	H2O	Psig	Psig	Psig	Psig	RPM	Ft Lbs	%	CFM	lb/hp-hr	hp	lb/hr
2300		2.75	23.35	21.04	28.41	12.07	3.38	65.00	1.18	8.23	10.75	2299.33	724.13	99.00	-7.78	0.38	317.02	121.18
2100		2.64	24.67	18.90	26.31	13.20	3.37	63.00	1.22	7.70	9.99	2099.28	886.10	99.00	-7.33	0.36	354.25	127.55
2000		2.55	24.71	17.61	24.26	12.63	3.51	62.00	1.22	7.10	9.33	1999.70	918.25	99.03	-9.14	0.35	349.63	122.15
1900		2.52	25.32	16.89	23.25	12.03	3.49	61.00	1.20	7.22	9.31	1899.90	974.58	99.00	-9.30	0.35	352.52	122.05
1800		2.47	26.39	15.94	22.96	9.80	3.58	60.00	1.30	7.34	9.31	1800.00	1033.15	99.00	-9.89	0.34	354.04	120.15
1600		2.33	26.78	13.87	20.02	10.06	3.22	58.00	1.30	7.59	9.36	1600.00	1177.08	99.00	-9.36	0.33	358.62	119.44
1400		1.97	24.47	10.47	14.69	6.03	2.39	55.00	1.40	7.80	9.38	1400.02	1197.42	100.00	-7.83	0.33	319.24	106.27
1300		1.84	24.27	9.37	14.10	4.60	2.34	54.00	1.50	7.88	9.38	1300.28	1196.77	100.00	-7.71	0.34	296.32	99.57
1200		1.67	22.68	8.15	12.32	4.07	2.03	53.00	1.50	8.18	9.57	1200.48	1184.32	100.00	-7.01	0.33	270.69	88.91
1100		1.31	17.69	6.20	7.95	3.49	1.60	51.00	1.60	8.11	9.44	1100.62	1059.33	99.82	-5.66	0.34	221.98	74.80
1000		0.97	12.40	4.47	4.16	4.29	1.20	50.00	1.70	8.31	9.54	1000.67	883.30	99.72	-4.54	0.35	168.29	59.39
800		0.55	7.25	2.27	2.85	0.48	0.98	41.00	1.80	8.60	9.69	801.00	616.52	100.00	-3.72	0.39	94.02	36.35
	DOC																	
2300		2.93	23.18	20.89	25.98	5.45	3.20	60.00	1.30	8.18	10.83	2299.12	695.32	100.00	-9.58	0.39	304.44	118.76
2100		2.77	24.59	18.99	23.98	5.85	3.11	58.03	1.30	7.45	9.95	2099.13	855.93	100.00	-9.41	0.37	342.13	125.29
2000		2.69	24.85	17.91	22.53	3.50	3.23	57.22	1.30	6.98	9.41	1999.45	880.07	100.00	-9.55	0.36	335.05	119.16
1900		2.61	25.47	17.10	21.51	2.92	3.15	57.00	1.36	7.09	9.41	1899.80	937.23	100.00	-9.29	0.35	338.98	119.38
1800		2.51	25.98	16.01	20.34	2.24	3.26	56.00	1.33	7.24	9.44	1799.98	995.68	100.00	-9.73	0.35	341.19	118.17
1600		2.33	26.60	13.80	18.03	1.31	3.17	54.00	1.40	7.50	9.49	1600.00	1135.12	100.00	-9.60	0.34	345.83	117.60
1400		1.96	24.16	10.72	12.86	-1.10	2.28	51.13	1.53	7.74	9.52	1400.02	1148.67	100.00	-7.59	0.35	306.24	105.49
1300		1.78	23.34	9.52	11.89	-1.10	1.99	50.00	1.61	7.83	9.56	1300.17	1138.43	100.00	-7.02	0.34	281.86	94.88
1200		1.57	21.87	8.34	10.39	-1.10	1.71	48.00	1.70	8.17	9.80	1200.42	1127.97	100.00	-6.48	0.34	257.83	88.10
1100		1.20	16.64	6.43	5.89	-1.10	1.21	47.00	1.80	8.27	9.81	1100.48	997.65	100.00	-5.16	0.35	209.04	73.33
1000		0.87	11.55	4.80	3.05	-1.10	0.90	44.22	1.81	8.23	9.71	1000.58	824.60	100.00	-4.21	0.39	157.10	61.58
800		0.45	6.99	2.78	2.30	-1.10	0.71	34.80	1.90	8.37	9.75	801.00	577.40	100.00	-3.74	0.45	88.05	39.29

ENGINE 2 – 100 hour HRJP-8 Performance Run, Standard and DOC Data Summary

HRJ RPM	100 Hrs Standard	Exhaust Port 1 Deg F	Exhaust Port 2 Deg F	Exhaust Port 3 Deg F	Exhaust Port 4 Deg F	Exhaust Port 5 Deg F	Exhaust Port 6 Deg F	Turbo Turbine Outlet Deg F	Air Cell Ambient Deg F	Air Filter Inlet Deg F	CAC Inlet Deg F	CAC outlet Deg F	Intake Manifold Deg F	Coolant Engine In Deg F	Coolant Engine Out Deg F	Oil Sump Temp Deg F	Fuel Beaker Deg f	Fuel Engine In Deg F
2300		1054.16	1075.76	1048.34	1041.99	1055.91	1038.03	829.10	68.40	76.61	346.81	111.33	106.04	184.56	196.49	237.58	66.74	88.43
2100		1099.10	1123.32	1101.32	1093.03	1096.16	1075.14	885.06	69.96	78.48	349.00	111.17	106.19	183.20	196.51	240.34	67.82	88.52
2000		1072.14	1095.10	1073.42	1066.95	1075.67	1053.83	864.94	69.62	77.43	343.44	111.52	106.74	183.30	196.60	240.17	68.80	88.64
1900		1066.24	1098.46	1078.74	1073.22	1086.63	1054.96	872.91	69.90	78.45	344.14	111.69	106.38	182.85	196.50	238.70	69.16	88.61
1800		1054.70	1092.43	1072.46	1064.12	1076.51	1048.07	862.14	70.05	79.12	348.75	111.67	106.70	182.41	196.51	238.57	69.06	88.65
1600		1070.90	1121.75	1105.43	1101.95	1119.60	1066.84	909.45	70.69	78.79	346.77	111.51	107.16	180.95	196.52	239.49	68.89	88.63
1400		1025.44	1092.66	1079.63	1081.03	1104.03	1033.88	924.50	71.41	79.19	324.25	111.86	108.01	180.40	196.53	239.83	68.78	88.74
1300		996.15	1064.21	1054.15	1054.43	1074.59	1005.69	896.11	70.66	79.23	323.40	111.50	107.84	180.28	196.50	239.24	68.62	88.51
1200		998.73	1073.85	1060.62	1055.88	1076.06	996.43	914.27	70.96	78.87	314.17	111.68	108.00	179.73	196.60	238.98	68.30	88.56
1100		997.82	1089.20	1071.64	1064.95	1082.53	1001.04	959.81	71.39	79.21	278.86	111.43	108.41	179.98	196.62	236.51	68.36	88.50
1000		1013.51	1097.22	1074.80	1066.55	1085.63	1004.85	995.73	71.45	78.62	236.39	112.08	109.09	180.39	196.45	233.51	68.22	88.19
800																		
	DOC																	
2300		1100.87	1116.45	1096.44	1099.32	1108.91	1106.71	869.01	115.66	122.19	406.69	149.24	142.71	206.63	219.56	262.43	74.79	178.81
2100		1147.25	1170.45	1149.73	1146.64	1155.64	1141.51	930.03	117.14	124.51	405.90	149.37	143.41	205.35	219.50	263.82	74.74	179.01
2000		1112.48	1132.34	1111.48	1109.43	1117.75	1102.39	892.21	118.53	126.02	406.75	149.38	143.38	205.44	219.50	263.70	74.10	179.74
1900		1113.72	1141.17	1117.62	1111.59	1130.88	1107.29	902.38	120.62	127.80	406.68	149.34	143.63	205.12	219.45	262.79	73.45	179.31
1800		1107.11	1141.82	1119.79	1119.54	1137.30	1103.54	910.48	121.21	129.12	406.49	149.29	143.55	204.50	219.44	262.40	72.95	178.97
1600		1122.35	1174.89	1155.28	1148.22	1177.43	1119.91	957.24	122.22	129.23	405.64	149.30	144.13	203.12	219.48	262.79	72.74	179.59
1400		1071.90	1142.75	1129.11	1129.08	1156.26	1078.27	969.19	121.78	128.99	383.61	149.08	144.67	202.58	219.48	262.17	72.70	179.52
1300		1055.96	1132.02	1115.46	1115.41	1144.19	1069.06	964.02	121.54	127.94	376.93	149.42	145.28	202.09	219.42	260.91	72.93	179.42
1200		1061.42	1140.18	1118.49	1112.28	1144.08	1064.55	975.82	123.29	127.88	369.97	149.37	145.82	201.45	219.24	260.84	73.69	179.24
1100		1068.13	1158.70	1130.38	1118.81	1147.29	1063.76	1025.78	120.99	123.52	330.24	149.53	145.62	201.91	219.35	258.45	73.45	178.53
1000		1072.83	1163.10	1143.51	1128.64	1157.34	1072.10	1079.71	120.97	124.18	283.81	147.30	143.18	202.00	218.91	254.91	74.21	178.05

HRJ	100 Hrs	Air LFE	Intake Manifold	CAC Delta P	Exhaust Bank 1 B4 Turbo	Exhaust Turbine Out	Crankcase	Oil Gallery	Fuel Engine Supply	Coolant Engine In	Coolant Engine Out	Dyno Speed	Dyno Torque	Throttle Position	Blowby	BSFC	BHP	Mass Fuel Flow
RPM	Standard	H2O	Psig	Psig	Psig	H2O	H2O	Psig	Psig	Psig	Psig	RPM	Ft Lbs	%	CFM	lb/hp-hr	hp	lb/hr
2300		2.52	24.51	20.77	11.20	12.06	7.15	63.00	1.15	12.75	15.30	2299.20	724.85	99.00	-12.99	0.38	317.36	119.95
2100		2.44	25.78	18.86	11.20	12.25	7.20	60.00	1.10	12.58	14.81	2099.42	880.73	99.00	-13.06	0.36	352.07	125.61
2000		2.36	25.78	17.61	11.20	11.65	6.89	59.00	1.17	12.12	14.20	1999.72	913.27	99.00	-13.89	0.35	347.72	120.83
1900		2.33	26.20	16.48	11.20	11.24	6.78	58.00	1.11	11.76	13.68	1899.85	967.82	99.00	-14.51	0.34	350.06	119.69
1800		2.28	27.15	15.76	11.19	9.61	6.79	57.00	1.20	11.54	13.34	1800.00	1024.12	99.00	-14.73	0.34	350.93	118.29
1600		2.15	27.64	13.89	11.11	9.30	6.36	54.00	1.20	11.52	13.04	1600.00	1167.00	99.00	-14.05	0.33	355.56	117.78
1400		1.83	24.66	11.22	11.19	6.14	5.06	52.00	1.20	11.55	12.85	1400.03	1188.97	99.00	-11.46	0.33	316.97	103.23
1300		1.72	24.42	9.77	11.10	4.59	5.02	50.00	1.30	11.50	12.69	1300.25	1181.92	99.00	-11.42	0.33	292.63	95.35
1200		1.51	22.87	8.19	11.10	4.08	4.52	48.48	1.39	11.61	12.70	1200.62	1171.92	99.00	-10.44	0.33	267.87	87.80
1100		1.17	17.92	6.34	11.10	3.80	3.51	47.00	1.40	11.56	12.55	1100.75	1041.58	99.00	-8.61	0.34	218.28	74.95
1000		0.88	12.79	4.60	11.10	3.84	2.71	45.00	1.45	11.55	12.47	1000.77	866.85	99.00	-6.95	0.35	165.17	58.36
800																		
	DOC																	
2300		2.85	24.78	20.53	10.50	8.34	6.86	57.00	1.20	10.31	12.82	2299.45	696.55	100.00	-14.79	0.39	304.96	117.78
2100		2.69	25.78	18.01	10.40	8.49	6.58	55.00	1.20	10.45	12.66	2099.43	849.70	100.00	-14.03	0.36	339.70	123.34
2000		2.61	26.07	17.20	10.40	6.23	6.51	54.00	1.20	10.48	12.56	1999.65	873.33	100.00	-14.18	0.35	332.52	118.00
1900		2.53	26.40	16.42	10.30	5.57	6.49	53.00	1.20	10.56	12.48	1899.83	924.03	100.00	-14.23	0.35	334.25	116.96
1800		2.44	26.72	15.48	10.20	4.71	6.47	52.00	1.20	10.66	12.46	1799.95	983.73	100.00	-14.21	0.34	337.12	115.72
1600		2.26	27.12	13.97	10.19	3.82	6.03	50.00	1.20	10.88	12.41	1600.12	1116.18	100.00	-13.44	0.34	340.07	115.32
1400		1.89	24.33	11.37	10.10	0.84	4.84	47.00	1.30	11.02	12.36	1400.08	1132.57	100.00	-11.28	0.34	301.95	102.46
1300		1.71	23.58	9.79	10.10	0.27	4.54	46.00	1.30	11.06	12.29	1300.37	1124.62	100.00	-10.73	0.33	278.45	93.19
1200		1.50	22.21	8.04	10.00	-0.71	4.23	44.00	1.30	11.25	12.37	1200.57	1111.00	100.00	-10.11	0.34	253.97	86.22
1100		1.15	17.33	6.42	10.00	-1.04	3.23	41.00	1.40	11.21	12.26	1100.72	981.37	100.00	-8.07	0.35	205.67	72.26
1000		0.81	12.16	4.84	9.98	-0.39	2.51	38.00	1.40	11.13	12.09	1000.73	811.13	100.00	-6.96	0.37	154.56	58.01

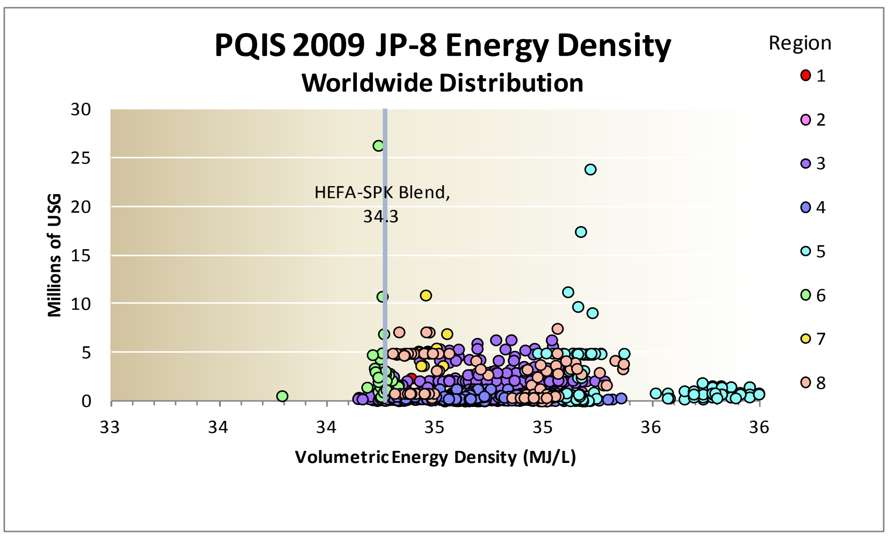
Appendix 4

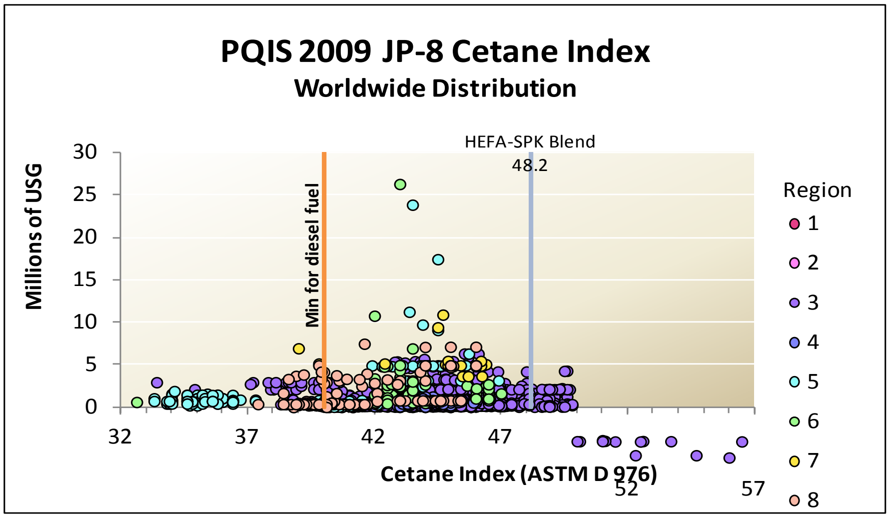
Fuel and Oil Analysis

Alternative Fuel Blend

The synthetic fuel used in this test was a 50%/50% volumetric blend of JP-8 and Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK). The blend was addititized with anti-oxidant, static dissipater additive, and corrosion inhibitor/lubricity improver per MIL-PRF-25017; requirements for the blend are found in MIL-DTL-83133 Rev H - Table I and Table B-II.

The following charts show the range of the volumetric energy density and cetane index of JP-8 worldwide as purchased by the Defense Logistics Agency-Energy (DLA-E) formerly Defense Energy Supply Center (DESC) in 2009. DLA-E property data for each batch of fuel is recorded in the Petroleum Quality Information System (PQIS). Each point represents one batch of fuel. Energy density is calculated using the fuels' density and lower heating values. The lower the energy density, the greater volume of fuel is needed to do the same amount of work. The energy density of this blend was at the lower end of the 2009 experiential range for JP-8. Cetane index is an indicator of ignition delay. Higher cetane values are often associated with engine performance benefits, including improved cold start performance. The derived cetane number of the blend was near the upper end of the 2009 experiential range of JP-8.





Engine 1, Fuel

JP-8 Fuel Sample Analysis Used for 400 Hour Data

JP-8 IAW MIL-DLT-83133G, Table 1					Sample ID
					WO#00921
					FL-14041-11
Property	Measurement	ASTM D	min	max	
Saybolt Color		156	report		14
Total Acid Number	mgKOH/g	3242		0.015	0.010
Aromatics	vol%	1319		25.0	15.5
Sulfur, total	mass %	2622		0.30	0.0928
		4294			0.0951
Distillation Temperature	°C	86			
	IBP		report		175.3
	10% recovered			205	193.2
	20% recovered		report		198.5
	50% recovered		report		210.7
	90% recovered		report		238.8
	FBP			300	259.5
	Residue, vol %			1.5	1.4
	Loss, vol %			1.5	1.1
Flash Point	°C	93	38		58.5
Density	kg/L @ 15°C	1298	0.775	0.840	0.8119
		4052			0.8111
Gravity	API @ 60°F	1298	37.0	51.0	42.7
		4052			42.8
Freezing Point	°C	7153		-47	-51
Viscosity @ -20°C	mm^2/s	445		8.0	5.351
Viscosity @ 40°C	mm^2/s	445	Not required		1.458
Net Heat of Combustion	MJ/kg	3338	42.8		43.2
Hydrogen Content	mass %	3343	13.4		13.8
Calculated cetane Index		976	report		44.0
		4737			45.2
Derived Cetane Number		6890	Not required		48.575
Copper Strip Corrosion		130		No. 1	1a
Thermal Stability		3241			
	change in press drop, mmHg			25	100.02

HRJP-8 Fuel Sample Analysis Used for 400 Hour Data

JP-8 IAW MIL-DTL-83133G, Table 1					Sample ID WO#00925 FL-14044-11
Property	Measurement	ASTM D	min	max	
Saybolt Color		156	report		3
Total Acid Number	mgKOH/g	3242		0.015	0.004
Aromatics	vol%	1319		25.0	10.5
Sulfur, total	mass %	2622		0.30	0.14
Distillation Temperature	°C	86			
	IBP		report		152.2
	10% recovered			205	172.4
	20% recovered		report		179.3
	50% recovered		report		202.0
	90% recovered		report		257.8
	FBP			300	273.9
	Residue, vol %			1.5	1.4
	Loss, vol %			1.5	0.6
Flash Point	°C	93	38		50.5
Density	kg/L @ 15°C	1298	0.775	0.840	0.786
		4052			0.786
Gravity	API @ 60°F	1298	37.0	51.0	48.4
		4052			48.4
Freezing Point	°C	7153		-47	-59.3
Viscosity @ -20°C	mm^2/s	445		8.0	4.54
Viscosity @ 40°C	mm^2/s	445	Not required		1.33
Viscosity @ -20°C	mm^2/s	7042		8.0	4.69
Viscosity @ 40°C	mm^2/s	7042	Not required		1.33
Net Heat of Combustion	MJ/kg	3338	42.8		43.6
Hydrogen Content	mass %	3343	13.4		14.4
Calculated cetane Index		976	report		51.15
		4737			53.45
Derived Cetane Number		6890	Not required		48.17
[illegible]		[illegible]		[illegible]	[illegible]

Engine 1, Fuel Viscosity and Density Values

FL-13803-10 - DF2 - Sample taken 15Dec10			
	25°C	30°C	79°C
viscosity	3.2858 cSt		1.3268 cSt
density	0.8377	0.8342	0.7992

FL-14041-11 - JP-8 - Sample taken 13Jul11			
	25°C	30°C	79°C
viscosity	1.8389 cSt		0.9200 cSt
density	0.8052	0.8012	0.7652

FL-14044-11 - HRJ/JP-8 - Sample taken off truck			
	25°C	30°C	79°C
viscosity	1.6387 cSt		0.8395 cSt
density	0.7797	0.7760	0.7393

Engine 1, Oil

Oil Sample Analyses for Engine 1 at 100 Hour Intervals

Maxxforce Engine

Sample Number		FL-13930-11	FL-13948-11	FL-13972-11	FL-13989-11	FL-14056-11
Work Order		WO#00869	WO#00892	WO#00909	WO#00916	WO#00929
Hours on Oil		0 hour	100 hour	200 hour	300 hour	400
ASTM D 5185 - Wear Metals by ICP (ppm)	MC-3891					
Ag		<1	<1	<1	<1	<1
Al		1.4	2.5	1.7	1.8	1.8
B	0	26.4	32.5	17.1	9.2	1.9
Ba	0	<1	<1	<1	<1	<1
Ca	2080 - 2770	2354.0	2477.0	2550.0	2554.0	2490
Cd		2.2	3.4	3.8	2.8	<1
Cr		<1	<1	<1	<1	<1
Cu		<1	24.8	16.9	10.8	7.4
Fe		11.7	75.8	41.0	34.8	25.9
K		<1	2.4	1.7	1.9	1.5
Mg	100 - < 300	282.5	292.2	301.7	304.7	303.2
Mn		<1	1.3	<1	<1	<1
Mo		<1	<1	1	<1	1.2
Na	0	2.3	3.2	3.4	2.5	2.3
Ni		<1	<1	<1	<1	<1
P	1150 - 1530	1223.0	1197.0	1192.0	1202.0	1211
Pb		1.0	1.9	2.1	1.7	1.7
Si		2.4	3.1	3.3	2.5	2.2
Sn		<1	<1	<1	<1	<1
Ti		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Engine 2 Fuel Analysis

JP-8 IAW MIL-DTL-83133H Table 1					WO-00995: 3 Apr 12 Sample Dated: 25 Jan 12 JP-8 from cell #2
Property	**Unit**	**ASTM D**	**min**	**max**	**FL-14266-12**
Saybolt Color		156	report		17
Total Acid Number	mg KOH/g	3242		0.015	0.0071
Aromatics	vol%	1319		25.0	16.9
Olefins			Not required		1.9
Saturates					81.2
Sulfur, total	mass%	2622		0.30	0.08
Distillation Temperature		86			
IBP	°C		report		169.6
10% recovered				205	194.6
20% recovered			report		200.9
50% recovered			report		215.3
90% recovered			report		242.9
FBP				300	263.9
Residue	vol%			1.5	1.5
Loss	vol%			1.5	0.6
Flash Point	°C	93	38		50.5
Density @ 15°C	kg/L	1298	0.775	0.840	0.8166
		4052			0.8164
Gravity @ 60°F	API	1298	37.0	51.0	41.7
		4052			41.7
Freezing Point	°C	7053		-47	-48.9
Viscosity @ -20°C	mm^2/s	445		8.0	5.7
		7042			5.7
Viscosity @ 40°C		445	not required		1.5
		7042			1.5
Viscosity @ 100°C		445			0.7
Net Heat of Combustion	MJ/kg	3338	42.8		43.2
Hydrogen Content	mass%	3343	13.4		13.7
Calculated Cetane Index		976	report		44.0
		4737			44.7
Derived Cetane Number		6890	not required		46.33
Copper Strip Corrosion		130		No.1	1A
Thermal Oxidation Stability		3241			
change in pressure drop	mm Hg			25	7.57
heater tube deposit	visual rating			<3	<4P
Existant Gum	mg/100mL	381		7.0	0.9
Particulate Matter	mg/L	6217		1.0	0.2
Water Separation Index		3948	70*		39
Fuel System Icing Inhibitor	vol%	5006	0.10	0.15	0.10
Fuel Electrical Conductivity	pS/m	2624	150	600	392
BOCLE Wear Scar Diameter	mm	5001	not required*		0.57

* = CI/LI additive spec requires that when added to fuel it will be able to meet a 0.65 max wear scar

Engine 2, Fuel Viscosity and Density Values

FL-14266-12 JP-8 from cell #2			
Sample dated 25 Jan 2012			
Received 2 Feb 2012			
Temp (°F)	Temp (°C)	Viscosity (cSt)	Density (kg/L)
77	25	1.9021	0.8092
86	30	1.7575	0.8061
175	79	0.9340	0.7699

FL-14290-12 DF-2 from cell #1			
Sample dated 10 Feb 2012			
Received 6 Mar 2012			
Temp (°F)	Temp (°C)	Viscosity (cSt)	Density (kg/L)
77	25	3.4464	0.8461
86	30	3.0887	0.8428
175	79	1.3686	0.8079

FL-14294-12 HRJ Blend from cell #6			
Sample dated 13 Feb 2012			
Received 6 Mar 2012			
Temp (°F)	Temp (°C)	Viscosity (cSt)	Density (kg/L)
77	25	1.6500	0.7733
86	30	1.5300	0.7700
175	79	0.8448	0.7334

Engine 2, Oil

Oil Sample Analyses for Engine 2 at 100 Hour Intervals

Navistar MAXXFORCE Engine #2,
HRJ Fuel Blend

Sample Number		FL-14094-11	FL-14117-11	FL-14202-11	FL-14209-11	FL-14257-12
Work Order		WO#00944	WO #00952	WO #00974	WO #00977	WO #00994
Hours of Engine Operation		0 hours	100 hr	200 hr	300 hr	400 hr
Hours on Oil	MC-3891	0 hours	100 hr	100 hr	100 hr	100 hr
ASTM D 5185 - Wear Metals by ICP (ppm)						
Ag		<1	<1	<1	<1	<1
Al		1.7	1.9	<1	1.6	1.7
B	0	<1	16.5	14.1	10.1	7.3
Ba	0	<1	1	<1	<1	<1
Ca	2080 - 2770	2393.0	2386	2447	2485	2548
Cd		1.2	1.9	2.0	3.5	1.7
Cr		<1	1.0	<1	<1	<1
Cu		2.4	26.7	18.1	12.1	18.0
Fe		7.6	92.4	63.3	32.1	28.8
K		<1	<1	<1	2.4	<1
Mg	100 - < 300	296.6	286.3	333.0	298.5	311
Mn		<1	1.8	1.0	<1	<1
Mo		<1	1.6	1.0	<1	<1
Na	0	3.4	5.4	4.3	2.5	3.1
Ni		<1	1	<1	<1	<1
P	1150 - 1530	1279	1173	1400	1238	1231
Pb		<1	3.4	2.1	<1	1.0
Si		4.0	5.3	4.3	2.1	3.2
Sn		<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1
V		<1	<1	<1	<1	<1
Zn	1260 - 1690	1379	1356	1444	1434	1456
ASTM D 664 - Total Acid Number (mgKOH/g)		3.035	2.965	3.004	3.769	3.01
ASTM D 4739 - Total Base Number	10.2	8.928	7.000	6.932	7.013	6.600
ASTM D 445 - Kinematic Viscosity @ 40C (cSt)	103.1 - 133.1	108.4	96.5	98.34	98.52	99.34
ASTM D 445 - Kinematic Viscosity @ 100C (cSt)	15.2 - 16.2	14.63	13.08	13.28	13.26	13.32
ASTM D 2270 - Viscosity Index		139.0	133.5	134.0	133.0	133.0
ASTM D 6304 - Water Content (%)		0.031	0.0065	0.006	0.004	0.008
ASTM D 3524 - Fuel Dilution		0.0000	0.0000	0.0000	0.0000	0.000
Soot Content by Soot Meter		0.0	0.1	0.1	0.1	0.2